BRITISH WELDING JOURNAL

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CONTENTS

Presidential Address:

Education in Welding
By E. Seymour-Semper

Metal Transfer in the Self-Adjusting Arc
By A. A. Smith and J. G. Poley

Fatigue Tests on Butt Welds in Mild Steel
By R. P. Newman and T. R. Gurney

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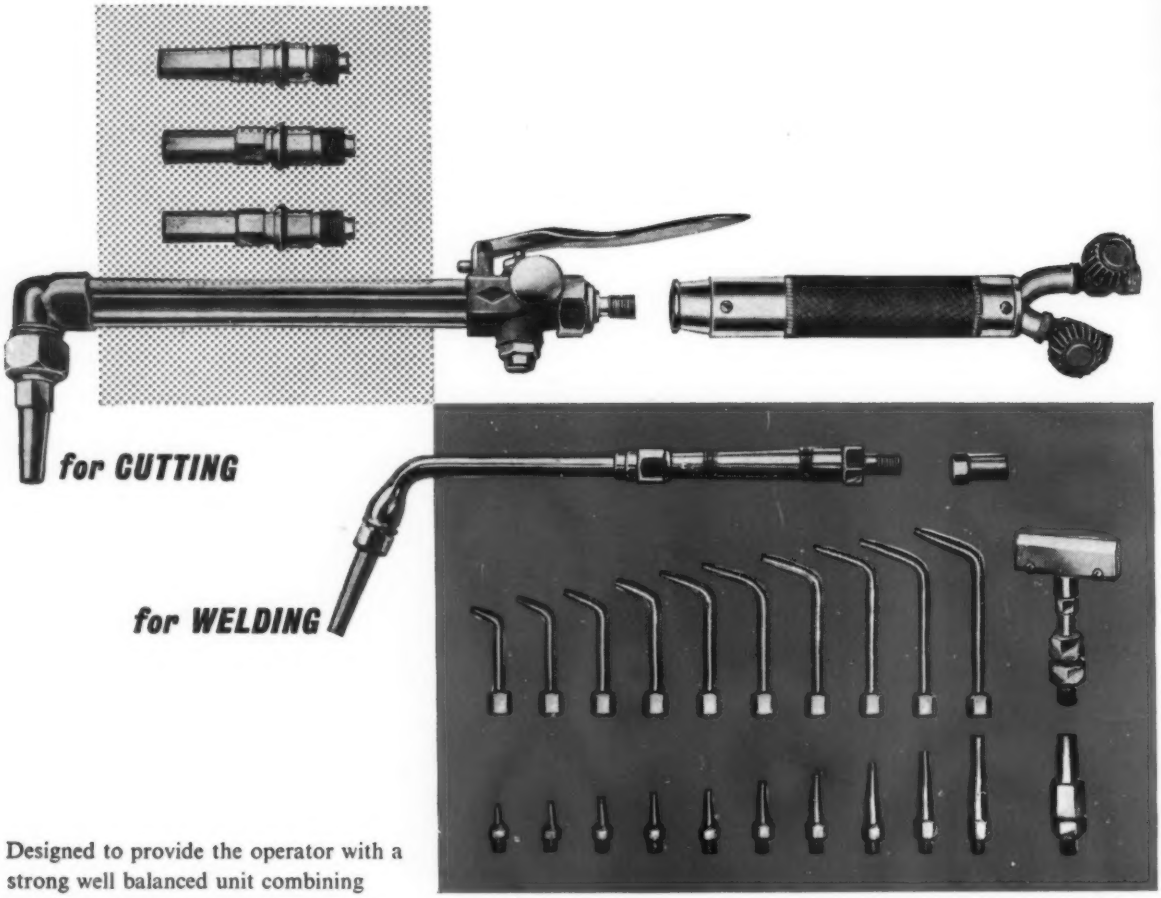

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Inside front cover

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Incorporating the *TRANSACTIONS* of the Institute and *WELDING RESEARCH*

CONTENTS

INSTITUTE OF WELDING

557 **Presidential Address: Education in Welding**
By E. Seymour-Semper

562 **Electric Welding: Will it Revolutionise the Methods of Boiler-Making?**

INTERNATIONAL INSTITUTE OF WELDING

564 **Chairmen's Reports for Commissions 3, 8, and 13**

BRITISH WELDING RESEARCH ASSOCIATION

565 **Effect of Wire Diameter on Metal Transfer in the Aluminium Self-Adjusting Arc**
By A. A. Smith and J. G. Poley

569 **Fatigue Tests of Plain Plate Specimens and Transverse Butt Welds in Mild Steel**
By R. P. Newman and T. R. Gurney

595 **Raising of Studs on Metal Surfaces** *By E. J. French*

599 NEWS AND ANNOUNCEMENTS

603 CURRENT WELDING LITERATURE

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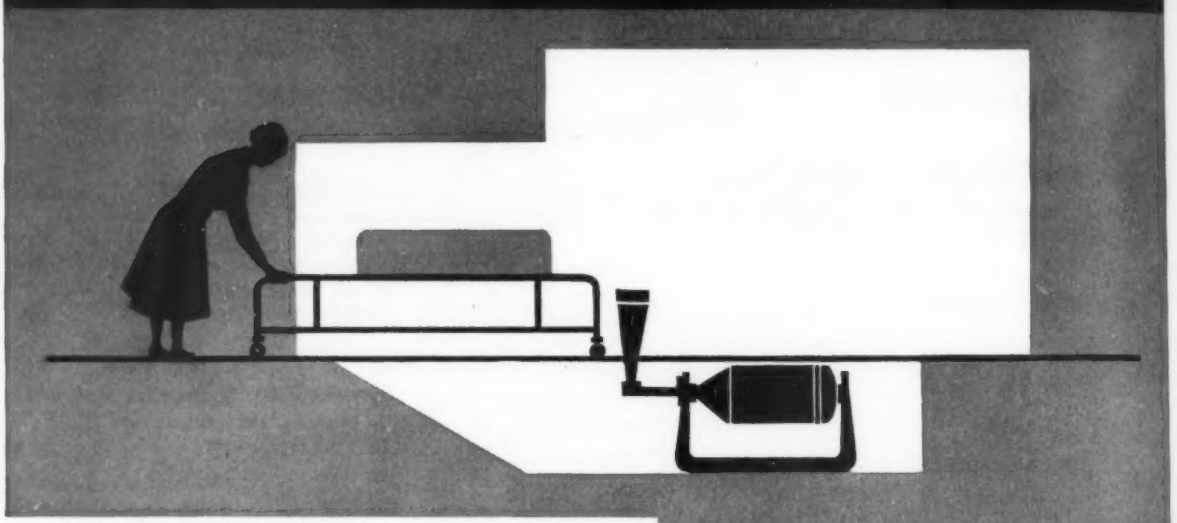

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PRESIDENTIAL ADDRESS

Education in Welding

By E. Seymour-Semper, M.I.MECH.E.

It has been usual for your President to make a contribution to thought and interest in welding by devoting his Address to some matter of technological interest. This year, however, it has seemed to me appropriate to follow another course and to speak to you about education in welding—a subject which vitally concerns everyone of us.

This is something which has been very close to my heart during my thirty-six years' membership of the Institute, and I have endeavoured to serve the cause first as a lecturer, then as an organizer, followed by some years as Chairman of the Institute's Education Committee, and latterly as Chairman of the Council's Committee which has created and fostered our already well-known School of Welding Technology.

I am now deeply grateful for the opportunity the Presidency affords for serving the interests of our members, and during my term of office I will endeavour to see that the School is developed to serve British and Commonwealth engineering to the full, and in so doing to make the Institute of Welding a greater and more influential body. An opportunity such as this has been awaited for many years; it may be compared with that presented to the Institute in 1935 when we were given the task of organizing a programme of welding research. The Council today will be just as determined as their predecessors were in 1935 to see that the opportunity is not missed.

It is perhaps also fitting that I should talk about welding education because the Autumn Meeting this year has been organized in collaboration with the French Society of Welding Engineers. We are very glad to welcome to the Meeting fifty members of this Society together with their President. As many of you know, France is renowned in Europe as a centre for advanced training in welding practice and technology, and students travel from many parts of Europe to take the Courses organized by the École Superieure de Soudure Autogene.

I WOULD like to survey, very briefly, the growth of welding in Great Britain, to examine what steps have been taken to provide educational facilities in welding technology during this period of expansion, and to consider to what extent these facilities have proved adequate.

The full curve shown in Fig. 1 is a rough indication of the rate at which the application of welding has grown over the past fifty years. The growth was smooth until the wartime peak of 1944; this was followed by a decline during the change-over to peace-time production, but the growth since 1950 has again been smooth and rapid.

In the early days, the use of welding was very limited and less critical than today, few processes were available and a very limited number of metals were commonly welded. The volume of welding knowledge available was not then very great. If I may again be permitted to be personal, I would mention that my own introduction to welding occurred at the University, when in the "Strength of Materials" Course, we had to pull some welded specimens on an old Buckton tensile testing machine. I was very intrigued with these specimens because the fracture always occurred outside the weld. When I did one day succeed in fracturing the weld metal, the coarse 'crystalline structure' provided the reason for this! When I endeavoured to find out whether the specimens were gas or arc welded, nobody seemed to know and my lecturer said—"Oh, they were just welded"! In those days, of course, there were only three welding processes—gas, arc, and resistance—whereas today the number of processes in use is probably ten to fifteen times that number. What tremendous progress in less than a lifetime! I doubt whether any engineering process has developed and expanded to such a great extent in such a short time—what a challenge to the Institute of Welding!

From about 1936 the position began to change, and

This Address was presented at the Autumn General Meeting of the Institute on Tuesday, 3rd November, 1959. 516

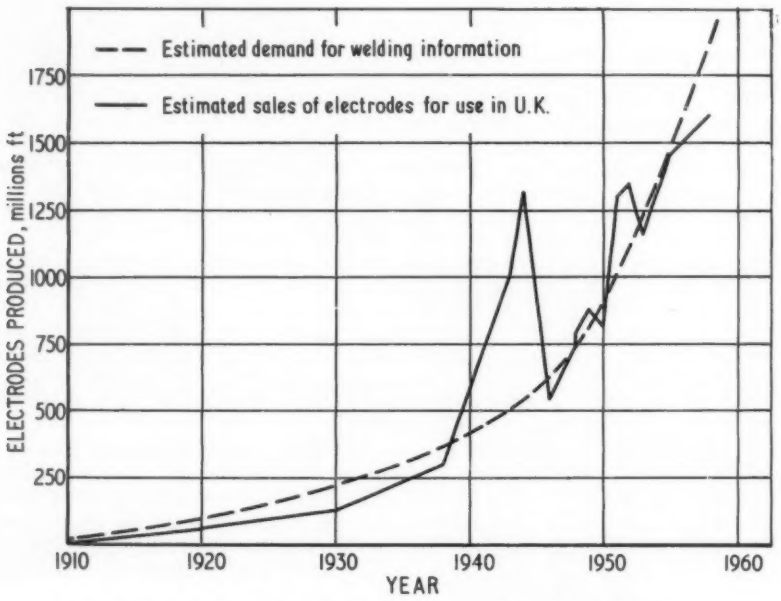
to change at an ever-increasing rate. Welding was applied to an ever-widening range of structures which had to withstand even more arduous service conditions; more metals were continually added to those that had to be welded commercially; new joining processes were introduced; special inspection techniques were developed to seek out the weld defects.

More knowledge was therefore required to apply welding properly and this brought with it a demand for information. The dashed curve in Fig. 1 shows my guess at how the knowledge required for the proper application of welding has increased over the past fifty years. I regret it is only my guess.

during the war at Stow College and at Portobello. There are still many in industry who remember gratefully the instruction received at these two Scottish centres.

However, the sum total of all this has been quite inadequate and our present efforts become more inadequate as our technology becomes more and more complex. Time for improvement is short and action is called for.

Before proceeding to discuss present facilities in more detail, I would like to examine the knowledge of welding required by different personnel in industry. These may be divided roughly into two groups: the



1—*Increase in sales of electrodes and demand for welding information*

We may now ask the question—"What steps were taken in Britian to meet the demand for information which this growth presented?" Much has been written of course, in the form of books and articles, and these went some way towards meeting this demand. Welding periodicals published in this country date back to 1903 when a journal called *Acetylene* appeared. Its name and scope were widened in 1912 to include lighting and welding, and in 1917 it became *The Acetylene and Welding Journal*. From 1922 to 1929, when it was discontinued, it was the *Welding Journal*. Another periodical published for some years by a well-known manufacturer of compressed gases was called *Industrial Gases*, and in 1933 a new journal called *Welding Industry* appeared. Later it became *Welding* and is now our well-known *Welding and Metal Fabrication*. Then in 1939 we had our own publication, the *Transactions of the Institute of Welding* which, of course, was succeeded by the current *British Welding Journal*. Good work has also been done by the Trade and Educational bodies, and I will examine their efforts later on. You will all, I am sure, wish to recall the Courses held

first a very small one composed of the welding specialists whose job it is to have as thorough a knowledge as possible about all joining processes and their relation to the engineering functions of design, manufacture, and inspection. So far only the larger organizations have appointed a full-time welding specialist to their staff but one hopes that their number will increase as the importance of welding specialization is realized.

I would suggest that a welding specialist should be a man who has the background of a full theoretical and practical training in engineering and/or metallurgy so that he may fully understand and appreciate the functions on which he will have to advise.

The second group is immense, and comprises all responsible personnel in the engineering industry who require an up-to-date working knowledge of welding and its problems for the proper discharge of their duties. I am sure you all agree that it is vitally important to our industrial future that all designers, draughtsmen, production engineers, senior works' staff, inspectors, and so on, should receive sufficient training

in welding and its related technologies to enable them to employ effectively the forty or more joining processes at their disposal, to get the best out of welding by proper design, to select the correct material, use the most suitable welding process, and see that an appropriate standard of inspection is adopted. Above all, we must ensure that they are kept aware of the problems which have to be anticipated so that they may seek advice before it is too late. Welding technology is developing so fast that this group must be kept informed of new knowledge; and the best way of doing this is by sending senior staff to 'Refresher Courses'.

Let us now look at the facilities which exist in the United Kingdom for training these two groups of people. Firstly, for the welding specialist we have very few facilities, and the experiments in further education which have been carried out in this field have not been very well supported. It seems to be generally agreed that specialization in welding should take place towards the end of an engineering education so that the provision of the knowledge required by the welding specialist should be made at post-graduate level, the student having attained graduate standard in engineering or metallurgy.

So far, only the Universities of Manchester and Cambridge have tackled this problem and I am advised that the Course at Manchester has been the only one covering the knowledge which would be required for the proper discharge of the responsibilities of a welding engineer. Why have these ambitious schemes not been supported as much as we might have expected? Some educationists say there is no demand for specialized welding education at so advanced a level and many graduates say they would like to avail themselves of the facilities if they were there. This looks a bit like the 'hen and the egg' conundrum, and if this is so, the Institute will have to break through it.

At the present time I feel that we must not expect to find a demand *from the individual student* for training for what is still an uncertain market for the young engineer. We must look to industry to send people for training and to support a scheme of the type which I will propose to you at the end of this Address.

Education of the craftsman does not really come within the scope of my argument, but I cannot leave specialized training in welding without mentioning the great work of the Welding Advisory Committee of the City and Guilds of London Institute and of the Technical Colleges which organize the Courses. A four-year syllabus is now in being which will provide the craftsman and junior staff with a sound understanding of the science and practice of welding.

As far as the second group is concerned, the facilities here, in the past, comprised:

Schools operated by the manufacturers of welding equipment

A few isolated courses at Technical Colleges

The Summer Schools organized by the British Welding Research Association.

The commercial schools have done, and indeed are doing, a most valuable job for operators, and for supervisory and design staff. There are basically two types of Course; one a training Course for welders and not relevant to the subject I am discussing today; the other a general Course for more senior people. Variations on the theme of the general Course are arranged to suit the requirements of particular industries. The Courses last two weeks or more, and are intended to give those attending a sound basic understanding of the welding processes marketed by the manufacturer concerned, and of the factors to be taken into account in their application. Special Courses for designers devote much of the time to design principles and their application to practice.

I would now like to pay tribute to the excellent work done by the British Welding Research Association through its famous Summer Schools. These Schools were held annually between 1950 and 1957 and were attended by about 250 people each year. There is still a gap in the "Welding Calendar" left by the passing of these Schools and I welcome the recent suggestion of an annual convention of British, and maybe Commonwealth welding specialists as a development of the Advanced Course for Welding Engineers held last September by the School of Welding Technology, at which we had a galaxy of welding specialist lecturers headed by Prof. Rykalin of Moscow.

At the Summer Schools, the experts mingled with the newcomers to welding, and lectures were given by leading personalities in a wide range of subjects. Until the formation of the School of Welding Technology, the Summer Schools probably did more than anything else to fill the gap in the welding knowledge of responsible engineers in British industry.

I would now like you to think back with me to the Conference on the "Education and Functions of Welding Engineers", held at Ashorne Hill in September 1956, for the brilliant conception of which credit is due to our Secretary, Mr. Guy Parsloe. Recent developments in the Institute's educational policy must be most gratifying to him after he has worked for so many years for the provision of higher education in welding.

At this Conference, you will recall, we examined the role of the welding specialist in industry and considered what was being done in Britain, Europe and America in providing the necessary training. I have already sketched briefly our own efforts but it would be stimulating to remind ourselves at this stage of what is being done in other countries.

In France, the Institut de Soudure conducts a recognized course of Training for those who have already had a basic engineering training, comparable with University Engineering Courses in the United Kingdom.

Norway devotes an appreciable amount of time to engineering courses in welding technology.

The Belgian Institute arrranges courses for welding engineers and for teachers of welding. They are most comprehensive.

In Denmark, the Welding Institute organizes a course for training and qualifying welding engineers.

The German Welding Association has a short course which aims to give qualified engineers a full understanding of welding and its application so that they may fulfil the function of welding engineers.

In Italy, the Welding Institute arranges a training course to provide industry with young engineers who have a good knowledge of welding technology. Practical work is an important part of this course.

Osaka University in Japan provides a six months'

course in welding engineering, more than half of which is devoted to practical work.

In Yugoslavia, the Welding Society has a comprehensive scheme for training all grades—there are practical courses for operators, special courses for engineers, and full training courses for welding specialists.

During his recent visit here Professor Rykalin told me that there are ten Universities in the U.S.S.R. which provide courses in welding, and the annual output is four hundred degree welding engineers. This course is of five years' duration, the first half being devoted to general engineering, with specialization in welding in the second half. Welding technologists of a standard roughly equal to our Higher National Certificate are being turned out at the rate of three hundred a year, but this does not nearly meet the demand for them in the U.S.S.R.

In the U.S.A. there is a Department of Welding Engineering at Ohio State University, which organizes a five-year programme leading to a degree in Welding Engineering. In his paper to the Conference, Professor Green told us that the demand for graduates far exceeds the supply—offers of posts sometimes number eight to ten per graduate, and some of the highest paid posts go to graduates of the Department—a rather different state of affairs from that in Britain! Other courses are offered at five other Universities, notably at Rensselaer.

A five-point announcement of the findings of the Ashorne Hill Conference was issued, the two of importance to us today being as follows:

> "1. *The Conference recommends that industry should encourage and support Courses of specialist study of welding processes and practice designed for men already professionally qualified as engineers and with some specialized industrial experience associated with welding. One-year post-graduate Courses in welding should be made more generally available and shorter full-time Courses should be tried, their value having been proved in other countries.*"
>
> "2. *The Conference urges the Council of the Institute of Welding, as representing the vast majority of those technically concerned with the use of welding in this country, to use its influence with Industry, the Universities and Technical Colleges and educational authorities generally, to forward the adoption of the policy recommended and so ensure the provision of welding instruction corresponding in scope and character with that already available in those highly industrialized countries with which the British engineering industry is in competition.*"

These findings, coupled with the desire of the British Welding Research Association to be relieved of the Summer Schools, and the success of the Institute's evening course on Structural Detail Design, led the Council to adopt the President's proposal to establish the School of Welding Technology in October 1957. We shall always thank Sir Charles Lillicrap for his wisdom and boldness in putting this scheme before us.

Before the establishment of the School, the first venture of the Institute into the field of direct technological education was in the autumn of 1956, when the Structural Sub-Committee offered the first Evening Course in London on the Detail Design of Welded Structural Steelwork. Although many influential members of the Institute had misgivings, the response was overwhelming—some three hundred designers and draughtsmen applied for enrolment, some prepared to travel to London each week from as far away as Bristol. This outstanding success has been a source of inspiration, and the Institute owes much to the foresight of the members of the Structural Sub-Committee who had the courage to forge ahead in spite of many forebodings of failure. The Course confirmed the need of industry for specialized training in welding technology, and the Institute had learned that it could, with some confidence, expect a good response to further ventures of this type.

Early in 1957 talks took place between the Institute and the British Welding Research Association about the possibility of the Institute relieving the Association of the distraction of the very successful Summer Schools. The purchase of our present headquarters allowed us to do this and to offer an opportunity for even more engineers to avail themselves of specialized training in welding.

It was agreed that, in the first instance, the purpose of the School would be the provision of technological instruction at a fairly advanced level for those holding responsible positions in industry, so that they might be provided with the most up-to-date information on welding design, fabrication, inspection, and research.

In October 1957 the first Course was held, dealing with pressure vessels and pipework. Between then and now, thirty day and evening Courses have been held and have been attended by more than 1600 senior personnel from industry. This is a fine achievement and represents a threefold increase in the number of students trained annually under the Summer Schools.

The lectures are given by leading experts from industry, the universities and research organizations, so that the School makes available to British industry a vast fund of technical information. It is continuously kept up-to-date by the fruits of research and experience and, during the first two years of the School, the knowledge of more than three hundred lecturers has been made available to Course members. Never before has such a co-operative effort been made in welding education.

The organization of the School has been no light task, and I should like to couple with my own appreciation the thanks of the members of the Institute to our Technical Officer and his assistant under the direction of Mr. Parsloe, for their enthusiasm, loyalty, and very hard work done in the early days under difficult circumstances.

The figures for attendances and lecturers are impressive but these alone are not sufficient. If the School is to become recognized as a teaching establishment of the very highest quality, those attending must be satisfied with the information which they receive. In the preparation of courses, it is necessary first to do some hard thinking to decide what information industry requires. Secondly, it is essential to know who can provide this information at the right standard. Thirdly, the students' individual requirements must be conveyed to the team of lecturers so that each course

may be 'tailor-made' to suit those who have enrolled.

So far so good: we seem to have made a successful start, but what of the future? Each year the need for technological education in welding for both of the groups of personnel previously discussed grows more pressing. There is clearly a need for some fundamental welding instruction to be included in every general engineering syllabus—this, however, is a long-term policy. We cannot afford to wait. The need is here and now, and it is the Institute's responsibility to see that action is taken.

The School offers a grand opportunity for serving British and, I hope, Commonwealth engineering. It is, however still only in the formative stages and it must grow quickly if it is to discharge the responsibilities which we have accepted. We must be bold. We must think 'big'. Before this is done, careful and perhaps tedious spade work is required to examine the problem and formulate a long-term programme to solve it. Our present success with the School has proved the overwhelming need for better long-term educational facilities, and we have now reached the stage when we must formulate a policy for several years ahead.

I hope the proposed Advisory Council on Education in Welding can be brought into being during the next few months and I shall ask it to get to work immediately in formulating a programme which will not only meet the demands of the present but take care of the opportunities of the future. In this I feel sure we shall have the support of the Council and the practical encouragement of all members of the Institute.

May I conclude by repeating a remark in my opening to this Address? The future of education in welding vitally concerns us all. But now I would add that it is also a matter of the greatest importance to the entire engineering industry, and indeed to the national economy. Engineering cannot live without welding and without good welding it cannot live well. We are passing through what with truth has been called the Second Industrial Revolution, which in a far-reaching way is transforming customers into competitors. That greatest of all Englishmen said recently, when planting a tree on the site of Churchill College to be named after him: "More than any other country in the world, Britain must rely on the enterprise and trained ingenuity of her people. The emphasis should be on the word 'trained'."

The Engineering Industry dare not entrust a vital group of production techniques to men who are handicapped by an incomplete understanding of their possibilities and limitations and do not measure up to or indeed overtop the welding specialists in other countries.

Our duty as an Institute is two-fold. Firstly, we must do all in our power to ensure that this national necessity is recognized and understood by the Engineering Industry and by the Government, so that welding is brought in at an appropriate place in the education of engineers and so that welding specialists are trained in adequate numbers. Secondly, it is our duty to back Government policy for technical education to the limit of our resources. We have made a start by the creation of our School of Welding Technology. What shape it will take will depend partly on the contribution to be made by Universities and Technical Colleges and partly on the resources of the Institute. It will be our main contribution, but we must also use and indeed make opportunities to co-operate with educational authorities and other organizations in this tremendous task. It is, as I have said, a matter of concern to welding and, therefore, to our Institute, but it is a matter of such importance that it should not be left to the unaided efforts of an Institute which, proud as we are of its achievements, we know to be as yet but a youngster among Engineering Institutions. I would plead with the older and established Institutions and with the Ministry of Education to consider whether it is not as much their responsibility as ours to ensure that industry has the men it needs to weld and to weld well.

Electric Welding

WILL IT REVOLUTIONISE THE METHODS OF BOILER-MAKING?

This article was written by Mr. A. H. Goodger when, as a very young man, he was working at Galloways Ltd., engineers and boiler-makers, of Manchester. He became interested in electric arc welding and started to experiment in various ways, making electrodes of many types, welding in hydrogen and carbon-dioxide atmospheres, and trying many other queer ideas. These usually came to an end through lack of funds.

The General Manager of the Company was a very able man, but because of the firm's great interest in riveting he thought that the suggestion to use welding as a method of construction was absolute heresy. It was for this reason that the article was originally published unsigned, for the author was afraid of losing his job!

"I HAVE no faith in electric welding," was a remark frequently made by authorities on engineering only a short time ago, but these authorities are being slowly convinced that there is a great future for the process.

It is true that electric welding has hardly yet reached the stage of ousting the riveting of high-pressure Lancashire boilers, but it is evident the time is approaching when it will be possible to apply the process to this and similar uses, and it may in the long run revolutionise the present costly method of boiler-making.

During the war the shortage of carbide for acetylene welding, the extreme difficulty of obtaining labour for riveting, and the pressing need for rapid output necessitated the use of electric welding in many new directions, chiefly in cases where no great tensile strength was required. Consequently the development of the process was more rapid than would have been the case under ordinary circumstances, and the numerous articles and papers on the subject in the technical journals showed that it had aroused extreme interest. After the Armistice there was a distinct lull, but during the past twelve months there has been a very decided increase in the amount of work turned out. In the Manchester district alone there are several large firms whose whole output consists of electrically-welded work. Their first attempts consisted of simple straightforward work, such as tanks, drums, and medium sheet steelwork of various descriptions, the majority of which had merely to be leak-tight and presented no very great difficulties. Gradually, however, both manufacturer and customer are beginning to realise that a considerably higher class of work can be tackled, and this has been shown by the greatly increased pressure tests to which these vessels made by this process are subjected. Then, where a short time ago the orders were for three or four vessels the majority of them now are for thirty or forty or more. The size of the individual products is increasing, too, and 30,000-gallon tanks for oil storage or railway transport are commonly made entirely by electric welding.

The majority of this work has been a direct transition from riveted work, not passing through the intermediate stage of acetylene welding. Already there are several designs of small boilers of the type used on steam waggons, in which a considerable portion of the work is to be done by electric welding in preference to riveting, and with increased skill on the part of the operators, or with improved appliances, there is little doubt that very considerable development will take place, but it would be unwise to suggest that this will be rapid. The stage of rapid development is over, and in future the improvements to be expected are those which will enable the worker to obtain results which will be absolutely reliable and can be guaranteed to stand the required tests. During the war this was not aimed at, but it will be found that the tests required will gradually become more severe.

The skill of the worker is one of the most important factors, and this is at present the limiting factor. So far there is no satisfactory method of judging the quality of a weld made by any of the electrical processes. Many brains have been at work attempting to discover such a test, but the results have been futile when applied to the work itself. The knowledge of the skill of the operator and the appearance of the finished

This article has been reprinted in full from the *Manchester Guardian* of Tuesday, 14th December, 1920, by kind permission of the proprietors of that newspaper. 512

work are at present the only guides, other than testing to destruction. This is, of course, impossible on finished work. Thus it will be seen that one relies on the personality of the man who does the work. He is the only one who actually knows whether the job is a good one or not. There has recently been considerable improvement in the matter of apparatus, tending to limit the possibility of bad work. In the majority of cases this takes the form of regulating appliances or resistances which prevent the operator from drawing out a long arc between the electrode and the work, the result being that he must maintain a short arc, and is therefore precluded from laying down oxydised or otherwise imperfect metal.

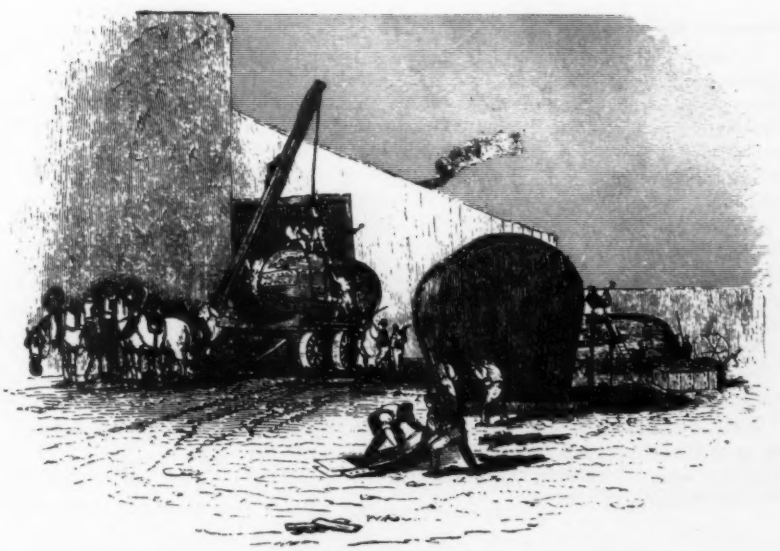
Probably it is on lines such as these that one must look for the most immediate improvements. For only by relieving the operator of the need for extreme care and from the strain of continual attention will it be possible to turn out work of a sufficiently reliable character to be used on articles to withstand high pressures—a matter of the utmost importance, particularly where failure would endanger life.

In these remarks the metallic electrode rather than the carbon arc process is the one in view. Though the carbon arc process has certain advantages, there is no doubt it is giving way before the other process, and that the field is occupied by the bare metallic electrodes or coated electrodes. The advantage of the bare wire is its cheapness, and little else. Considerably greater skill is required in its use, and it is not suitable for use with alternating currents. The future lies with the coated electrode, on account of the ease of working, the satisfactory quality of the metal deposited, its suitability for alternating or direct currents, and the ease with which vertical and overhead work can be done. The great drawback of coated electrode is the expense, its cost being five or six times the value of the wire it is made from. With the advent of a really cheap and satisfactory electrode the potentialities of the process are enormous, and there is no reason why such an electrode should not be produced. Repair work offers a tremendous field, and it is being very largely taken up. The possibility of rapidly replacing worn metal or repairing breakages is a great advantage to the engineer. Grooving in the flues of Lancashire boilers has founded a class of firm which specialises in boiler repair work by electric welding. They have their whole appliances mounted on a motor-lurry, so that they can be run to the place where the repair is required and the work can be executed in the shortest possible space of time and without the necessity for removal of the damaged part.

The prejudice of boiler insurance companies is gradually being overcome. Most companies are now ready to accept electrically-welded work, and in many cases are the first to suggest that such work should be done. Failures when in the hands of a good worker are rare, and the saving in cost as compared with a repair done by a boilermaker is generally very great, while the saving of time is the greatest of all advantages. In most cases the boilermaker would take about six times as long to do the job.

When it is realised that it is not necessary to have cast-iron in the weld of a cast-iron job, but that steel can be used, it will be seen that there is room for the development of a very useful practice in the repair of broken cast-iron. A number of firms have recently realised this. They use the coated metallic electrode composed of some suitable quality of steel and turn out most satisfactory work. Repairs of very heavy cast-iron work, such as parts of engine bed-plates, mill gearing, heavy machine tool framework, &c., have been done with success at a fraction of the cost of a new part.

The greatest obstacle to progress in the use of electric welding is the present attitude of labour. If the boilermaker applies electric welding to his work, his society will limit the rate of operation until there is practically no competition between it and riveting. Where it is possible to employ non-union labour the process proves itself a great economiser both of time and money.



Boilermaking one hundred years ago. A wood-engraving from "The Museum of Science and Art" by D. Lardner, published in 1859.

INTERNATIONAL INSTITUTE OF WELDING

Reports of Commissions –1959

Abridged versions of the Chairman's reports for three Commissions of the IIW are given below. These review the activities of the Commission following the Annual Assembly held at Opatija, Yugoslavia, in June 1959.

Copies of the complete authorized reports may be obtained from the Technical Secretariat, International Institute of Welding, 32 Boulevard de la Chapelle, Paris XVIII^e.

Commission III: RESISTANCE WELDING

(Chairman – Dr. H. G. Taylor)

Classification of Spot Welds

Sub-Commission F is to prepare recommendations for the classification of spot welded joints in mild steel rather than of the individual spot welds themselves. It is considered that though only one quality of weld should be recognized there are many instances in practice when a proportion of defective welds in a joint may be accepted.

Repair of Resistance Welded Assemblies

Studies are to be made of the repair of defective welds made in production and of assemblies that have been damaged in service. Papers on the repair of railway rolling stock, motor coaches, and aircraft are promised for the 1960 Assembly.

Non-destructive Testing

A Sub-Commission, including members from Commission V, is to be set up to study various methods of non-destructive testing of spot welds, which would avoid the need to destroy partly constructed and expensive assemblies. The Italian delegates suggested the preparation of standard radiographs of faults similar to those made for arc welds.

Welding Primers

Several offers have been made of information on the use of primers to protect the interior surfaces of spot welded assemblies, and it is likely that a comprehensive report can be prepared.

Productivity

Sub-Commission E will probably be able to report on its work at the 1960 Assembly. It will deal with the hourly output of welding machines and the measurement of welding variables.

Reports

A code of good practice for the projection welding of low-carbon mild steel (III-103-58) has been recommended for publication. Doc. III-104-59, relating to terms used in the electronic control of resistance welding machines, has been passed to Commission VI.

A report on satisfactory series welding with multi-electrode press welders (III-105-59), by the U.S.A. delegation, has been received; the U.K. delegate is to report evidence of unreliability.

A report on the flash welding of light alloys is to be presented at the 1960 Assembly by the Belgian delegate.

Commission VIII: HYGIENE AND SAFETY

(Chairman – L. André)

Health and Safety Handbook

After making some small amendments the Sub-Commission dealing with this Handbook has completed its work and has been disbanded. The book has been drafted in response to a demand for practical guidance on the precautions necessary to ensure health and safety in the practice of welding and cutting. The contents are of a purely practical nature and will appeal to the welder, cutter, foreman, and supervisor.

Reports

Various other activities of the Commission have now been subdivided among different members. Reports have been presented on the risk from carbon dioxide in CO_2 welding; the influence of the colour of walls, especially the capacity of different surface treatments to absorb ultraviolet radiation; transmission factors for welding glasses; the risks from ozone in arc welding.

(Cont'd on p. 598)

Welding
RESEARCH

B.W.R.A. REPORT

Effect of Wire Diameter on Metal Transfer

IN THE ALUMINIUM SELF-ADJUSTING ARC

By A. A. Smith, B.SC., A.I.M.,
and J. G. Poley

Using constant conditions of automatic welding, experiments were carried out to determine the effect of wire size on metal transfer in self-adjusting argonarc welding. In particular, the entry into the sub-threshold (globular transfer) range was investigated by measuring the burn-off characteristics of G1C aluminium wires from $\frac{1}{64}$ to $\frac{1}{8}$ in. diameter.

The results showed that the critical current below which spray transfer reverts to sub-threshold transfer (unsuitable for welding) is directly proportional to the wire diameter. Thus it is possible to use thin wires in the self-adjusting arc process if means are available for feeding the relatively fragile wires at high speeds.

Using such thin wires it is possible to weld thin gauge materials at higher speeds than those normally possible with the argon tungsten-arc process.

PREVIOUS work[1] has shown that in self-adjusting arc welding with $\frac{1}{16}$ in. dia. aluminium wire the mode of material transfer from the electrode abruptly changes from a rapid stream of small droplets, called 'spray transfer', to a large intermittent globular transfer when the wire feed rate is reduced below a critical value. The range where this globular transfer exists has been termed the 'sub-threshold range', and represents a current/wire-feed range which is unsuitable for welding. For $\frac{1}{16}$ in. dia. G1C wire, the sub-threshold range exists below about 115 in./min (or 100 amp) and consequently welding cannot be performed below this current with the self-adjusting arc process using this wire diameter. In practice, a smaller wire, such as $\frac{3}{64}$ in. dia., has been used to obtain a small extension of the operating range, but in general the argon tungsten-arc process is commonly used for the welding of thinner materials at low currents.

In the present work, the effect of the wire diameter on the entry into the sub-threshold range has been examined by the measurement of the burn-off characteristic of the wires, and the droplet transfer frequency over a range of wire feed rates. The suggestion by Houldcroft[2] that the 'critical' current below which spray transfer cannot exist is proportional to the wire diameter, rather than the cross-sectional area, has been investigated for a range of diameters of G1C pure aluminium wire.

Test Technique

Bead runs were made by automatic welding on degreased and scratch-brushed P.I.C. pure aluminium test plates using $\frac{1}{64}$, $\frac{1}{32}$, $\frac{3}{64}$, $\frac{3}{32}$ and $\frac{1}{8}$ in. dia. wires. To maintain a proper weld pool it was necessary to use $\frac{1}{8}$ in. sheet for the tests with $\frac{1}{64}$ in. dia. wire, and $\frac{1}{4}$ in. plate for tests with $\frac{1}{32}$ in. wire. For all other wires $\frac{1}{2}$ in. plate was used. Self-adjusting arc welding units were used to drive the various sizes of wire, and a constant-potential motor generator was used for all the tests. The welding head was mounted over the test plate, which was mechanically traversed relative to the arc.

Test constants used throughout the work were: d.c. current, electrode positive: torch angle 80°*; gas

Report A1/4/58 of the British Welding Research Association issued to members in April 1959.

Mr. Smith is a Principal Scientific Officer and Mr. Poley an Experimental Officer with the Association. 504

* Torch angle is defined as the angle between the electrode wire and the deposited bead surface.

nozzle ½ in. from the plate with the guide tube recessed appropriately to avoid contact when the arc becomes excessively long in the sub-threshold range; argon flow 60 cu.ft/hr; ratio of wire feed rate to traverse rate 10:1; arc voltage 22 V.

Current, voltage, and weld time were recorded automatically, and the wire feed rate was preset or computed from a revolution counter mounted on the wire feed rolls. Oscillographic records were taken of the arc voltage using a double beam oscilloscope coupled with a drum recording camera. Metal transfer data were derived from an analysis of the oscillograms, where each 'saw-tooth' period corresponded to a globule transfer period in sub-threshold range and voltage 'pips' indicated the occurrence of droplet transfer in the spray region.

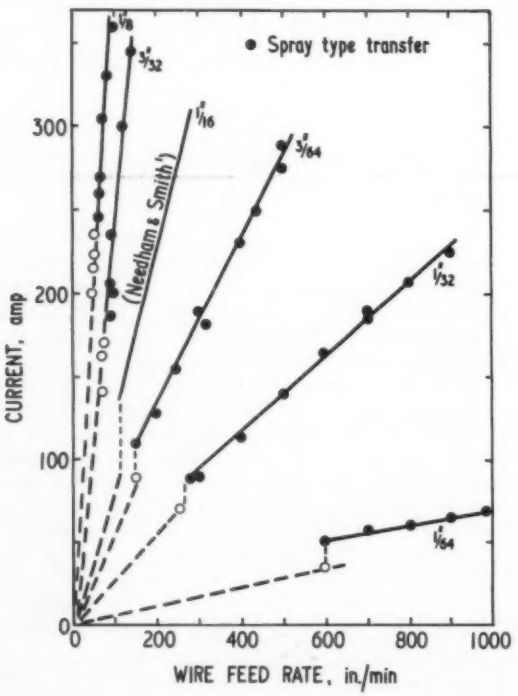
For a given wire diameter, a suitably high wire feed rate was preset to give a fine spray type transfer; subsequent tests were made at a progressively lower wire feed speed until the arc was seen to be in the sub-threshold range, *i.e.*, with globular transfer.

Experimental Results

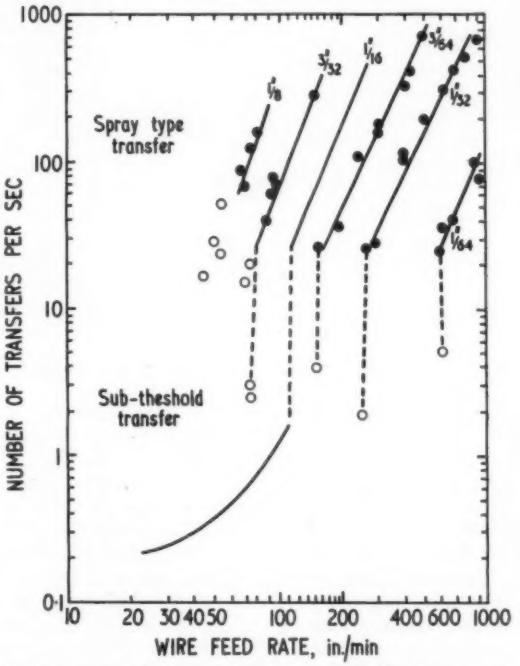
The relationship between current and wire feed rate for the various wire sizes is shown in Fig. 1. For the thinner wires a large change in wire feed rate is needed to produce a small change in current. For example, with $\frac{1}{64}$ in. wire, the feed rate was increased from 600 to 1000 in./min to give a change of current from 50 to 70 amp. With the largest wire examined, ⅛ in. dia., quite a small change in wire feed rate, from 125 to 150 in./min, produced a large current change, from 200 to 360 amp.

With all wires up to $\frac{1}{16}$ in. dia. the normal spray type transfer was maintained down to a minimum current when, for the same wire feed rate, it was possible to obtain two values of current, the test at the lower current being associated with the sub-theshold globular transfer. With the $\frac{1}{64}$ in. wire, for example, at a feed speed of 600 in./min the material transfer was the normal spray type at 50 amp, but a sub-threshold globular type at 35 amp. The sub-threshold transition was less obvious on the current/wire-feed-rate curves for the $\frac{3}{32}$ and ⅛ in. dia. wires than with the smaller wires because of the steepness of the slope.

Figure 2 shows the relationship between the wire feed rate and the droplet transfer rate for the different wire diameters. In the normal welding range, where spray type transfer exists, the transfer frequency increases rapidly with increasing wire feed rate for each wire size. As the size is reduced from ⅛ to $\frac{1}{64}$ in. dia. the wire feed rate must be increased some tenfold to result in the same droplet transfer rate. The transition from normal spray transfer to sub-threshold conditions



1—*Burn-off characteristics of G1C aluminium wires*

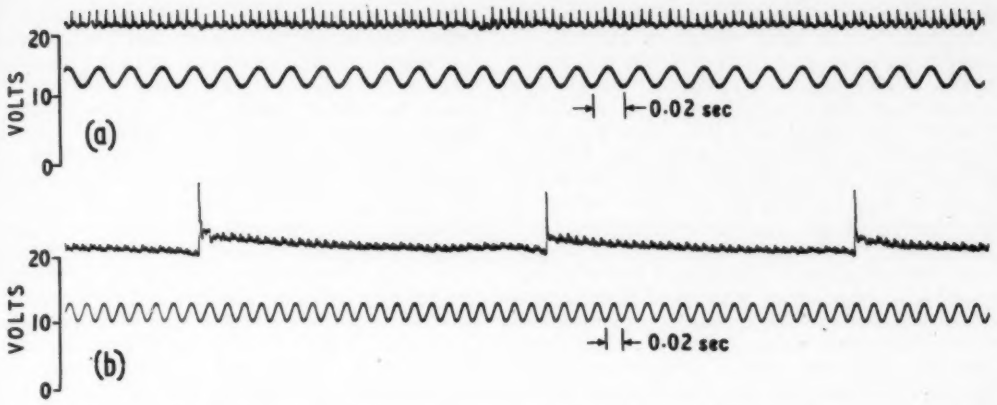


2—*Frequency of material transfer for G1C aluminium wires (1/16 in. wire: Needham & Smith¹)*

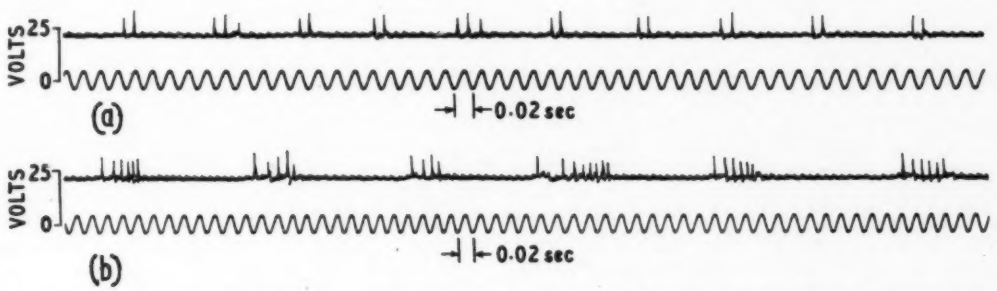
is generally indicated by the sudden decrease in the transfer rate.

Typical oscillograms of the two basic transfer types are shown in Fig. 3, where the rapid transfer rate in the normal spray type range is shown at (*a*), whilst the typical 'saw-tooth' wave form of the sub-threshold type at low current is shown at (*b*).

Examples are shown in Fig. 4 of the more complicated type of oscillogram obtained with the ⅛ and $\frac{3}{32}$ in. dia. wires at low wire feed rates, where the change from spray transfer to sub-threshold globular



3—*Oscillograms of arc voltage showing metal transfer types*: (a) *spray-type transfer, 180 transfers per sec., $\frac{3}{64}$ in. dia. wire at 180 amp;* (b) *sub-threshold type transfer, 2$\frac{1}{2}$ transfers per sec., $\frac{3}{32}$ in. dia. wire at 150 amp*



4—*Oscillograms of arc voltage showing multiple peaks obtained at low wire feed rates:* (a) *double transfer peaks, $\frac{1}{8}$ in. dia. wire at 220 amp, 58 in./min;* (b) *multiple transfer peaks, $\frac{3}{32}$ in. dia. wire at 215 amp, 50 in./min*

transfer was taking place. Instead of the normal single voltage peaks equally spaced at regular intervals, double (*a*) or multiple (*b*) voltage peaks occurred, followed by periods when no transfer could be detected. With $\frac{3}{32}$ in. wire, at the same wire feed rate, both sub-threshold and spray transfer occurred, but with $\frac{1}{8}$ in. wire it was not possible to maintain the sub-threshold condition for measurements to be made.

The lowest current below which the regular spray transfer cannot be maintained, called the 'critical current', is plotted for each wire size in Fig. 5. The relationship applying to the range of wire diameters investigated may be represented by a straight line of the form

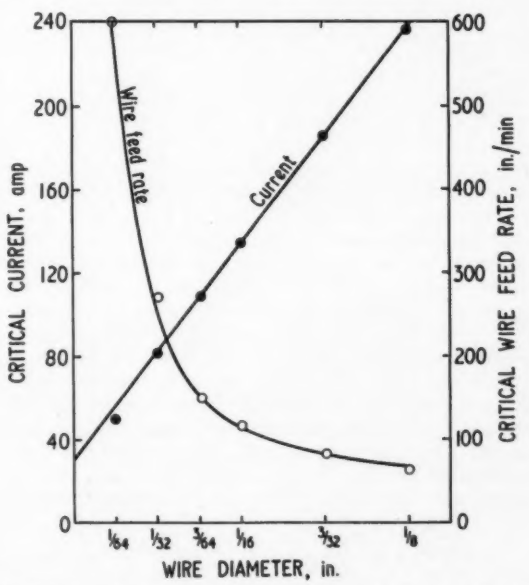
$$I_c = 1730d + 30$$

where I_c is the critical current and d is the wire diameter in inches.

The wire feed rate corresponding to the critical current for each wire diameter is also plotted in Fig. 5. This graph therefore represents the three-dimensional relationship between critical current, wire diameter, and wire feed rate.

Discussion

This work has determined the change from a spray to a sub-threshold type transfer for pure aluminium wire smaller than $\frac{1}{16}$ in. dia. with a fair degree of accuracy from a consideration of the characteristic changes in the burn-off characteristic and droplet transfer frequency curves. With wires larger than $\frac{1}{16}$ in. dia., the change is less clearly marked in either the burn-off characteristic or the droplet transfer



5—*Relationship between critical current, wire feed, and wire diameter*

frequency. Since only a relatively small change in wire feed rate results in a large change in current, the experimental technique becomes difficult, and errors due to wire feeding can be significant. It was difficult therefore to locate the change from spray transfer to sub-threshold type transfer with the $\frac{3}{32}$ and $\frac{1}{8}$ in. wires as precisely as with wires smaller than $\frac{1}{16}$ in. dia. The complicated form of the voltage oscillograms in the change region suggests, however, that stable conditions are not present with large diameter electrodes at these low currents. Needham and Smith[1] have already observed this type of metal transfer at low wire feed rates with $\frac{1}{16}$ in. wire, when high-speed photography confirmed that double voltage peaks on oscillograms occur after the transfer of a droplet, possibly larger than average, when two smaller droplets are subsequently detached from the fluid tip of the electrode wire. The conditions existing at the molten tip of $\frac{1}{8}$ and $\frac{3}{32}$ in. electrode wires may not allow the normal forces (such as the magnetic pinch effect, which is inversely proportional to the square of the diameter and proportional to the square of the current) to detach the droplet in the usual manner, and may be responsible for the less precise change from spray transfer to sub-threshold transfer. In the present analysis of the oscillograms, all voltage peaks have been counted to provide the metal transfer data, and the curves shown in Fig. 2 were compiled on this basis. The lowest frequency points on the curves for $\frac{1}{8}$ and $\frac{3}{32}$ in. wire in Fig. 2, although falling in the spray transfer region, were not consistently regular spray transfer and have, therefore, been shown as hollow points as adopted for the sub-threshold region. The critical currents for these large diameter wires have been defined, therefore, as the lowest current at which regular spray transfer occurs. These values for critical current have been used to derive the curves shown in Fig. 5.

The relationships shown in Fig. 5 thus provide the basic information governing the size of the filler wire which must be chosen to allow self-adjusting arc welding with G1C aluminium wire to be carried out with the desirable spray type transfer. Any chosen operating current point must lie above the critical current line, and the vertical intercept with the wire feed rate curve will specify the minimum wire feed rate below which the chosen wire size cannot be used. The effect of reducing the size from the usual $\frac{1}{16}$ in. dia. clearly has considerable practical significance in the self-adjusting arc welding of aluminium, because it has been shown that the process can be operated at considerably lower currents, whilst still maintaining the spray type of metal transfer necessary for satisfactory welding. The use of the self-adjusting arc can therefore be extended into a range of currents normally confined to the argon tungsten-arc process. For standard $\frac{1}{16}$ in. dia. G1C aluminium wire the limitation by the reversion to the sub-threshold condition of metal transfer prevents the use of the currents below 130 amp, whereas with $\frac{1}{64}$ in. wire the process still operates with a spray transfer at 50 amp. At this current, fillet, lap, and butt joints can be made in 16 s.w.g. aluminium sheet, using the manual self-adjusting arc process at much higher welding speeds than are possible with the conventional manual argon tungsten-arc process. In practice, it is necessary to choose a current slightly above the critical current curve shown in Fig. 5, to ensure that spray transfer is consistently maintained.

The wire feed rate necessary to exceed the critical current (Fig. 5) increases rapidly as the wire is reduced beyond $\frac{3}{64}$ in. dia. The critical wire feed speed for the standard $\frac{1}{16}$ in. G1C aluminium wire, for example, is about 110 in./min, whereas it is 600 in./min for $\frac{1}{64}$ in. wire. This asymptotic region of the curve suggests that for even finer wire sizes the wire feed rate required to produce a spray transfer would be extremely high and might be difficult to attain in practice, especially when the fragile nature of such fine wires is considered. But the slope of the burn-off characteristic for $\frac{1}{64}$ in. wire, shown in Fig. 1, indicates that, since quite a wide range of wire feed rate only slightly affects the welding current, some latitude in wire feed speed can be tolerated. Special equipment will be necessary for self-adjusting arc welding with small diameter aluminium wires because their fragile nature precludes the present arrangement of pushing the wire through a flexible hose from the wire driving mechanism. The present tests were made with special mechanized equipment where the distance between the driving rolls and the current contact tube was made small. Welding equipment employing drive rolls mounted in the gun itself that pull the wire from the reel should overcome most of these difficulties for manual welding.

Conclusions

The most important conclusion to be drawn from this work is that the critical current below which the spray transfer reverts to sub-threshold transfer, unsuitable for welding, is proportional to the wire diameter. For G1C aluminium wire this relationship may be represented by an equation of the form

$$I_c = 1730d + 30$$

where I_c is the critical current below which spray transfer does not exist at an arc voltage of 22 V, and d is the wire diameter in inches.

This relationship has been established in argon for a range of wire diameters from $\frac{1}{64}$ to $\frac{1}{8}$ in., using G1C aluminium wire.

The use of a wire smaller than the standard $\frac{1}{16}$ in. dia. commonly used for self-adjusting arc welding of aluminium extends the use of this process into a lower current range and makes possible the welding of thin gauge materials at higher speeds than those normally achieved with the tungsten-arc process.

REFERENCES

1. J. C. NEEDHAM and A. A. SMITH: *Brit. Welding J.*, 1958, vol. 5, pp. 66–76.

2. P. T. HOULDCROFT: *Weld. Met. Fab.*, 1953, vol. 21, pp. 58–61; 99–102.

B.W.R.A. REPORT

Fatigue Tests of Plain Plate Specimens and Transverse Butt Welds in Mild Steel

FIRST INTERIM REPORT
OF AN INVESTIGATION
INTO THE FATIGUE
STRENGTH OF BUTT WELDS
IN MILD STEEL PLATE

By R. P. Newman, A.M.I.MECH.E.,
and T. R. Gurney, M.A.

The report describes the results of fatigue tests on a comprehensive series of butt-welded specimens in mild steel plate to BS.15. The effects of (a) the method of edge preparation, (b) stress-relieving, and (c) shape of weld reinforcement, have been considered, and the various fatigue strengths obtained have been related to that of the plain plate.

Fatigue tests on plain plate to BS.15 in two thicknesses, and on ND I and ND IV grades of notch ductile steel to BS.2762 are also described.

Finally, comparisons are made with the reported results of other investigations of the same kind.

In 1950 the FE.8 Committee of the B.W.R.A. recommended an investigation of the fatigue strength of welded joints in mild steel plate. This recommendation was made at a time when the Association had decided to install a fatigue testing machine; this, for the first time, would permit the committee to plan a programme of axial load tests on specimens of reasonably large cross section. The need to obtain experimental data from axial load tests, carried out on specimens of essentially simple type, arose from the fact that while comprehensive data were available from other countries, nothing comparable existed for British materials such that basic fatigue strength values could be confidently stated. Further, the Committee recognized that the problem of the influence of weld quality on fatigue strength was, with the growing use in industry of radiographic methods of weld examination, becoming of quite general interest. The problem was one which clearly demanded that any experimental tests should be made on the elemental rather than the structural scale and, in planning the present work on good quality joints, it was foreseen that a control basis would be provided for the later study of the effects of weld faults.

The first part of the programme that was formulated comprised the testing of several types of transverse butt joint, with corresponding tests on unwelded plates for defining material properties. Two thicknesses of mild steel plate, $\frac{1}{2}$ in. and $1\frac{1}{4}$ in., were selected to enable various butt joint details to be included. Altogether seven joint details covering both hand and machine welding were proposed, the actual forms of joint being taken from recommendations made by the shipbuilding industry through the FE.21 Committee of BWRA. In addition, the Research Board recommended the inclusion of plain plate tests on two notch ductile steels.

This report contains the results of the various tests carried out for the initial programme.

Test Specimens

Material

The mild steel material complied essentially with BS.15 (Structural Steel for Bridges, etc., and General

Table I

Analysis of BS.15 plate material

Element,	%	*Element*,	%
C,	0·185	Cr,	0·05
Si,	0·05	Mo,	0·03
S	0·030	P,	0·023
Ni,	0·10	Mn,	0·57
		Cu,	0·12

Report D2/3/58 of the British Welding Research Association, issued to members in March 1959.

Mr. Newman is Chief Research Engineer, and Mr. Gurney a Senior Research Officer with the Association. 480

Table II

Mechanical properties of BS.15 plate material
(BS.18 test piece A. Each figure average of three tests)

Plate Thickness	*End*	*Yield Stress, tons/sq.in.*	*U.T.S. tons/ sq.in.*	*Elong. on 8 in., %*	*Equiv. Elong. on $4\sqrt{A}$*
½ in. No. 1	A	17·6	28·1	27·0	37
	B	18·2	28·2	28·0	38
½ in. No. 2	A	18·6	28·6	29·0	39
	B	18·0	29·0	27·0	37
½ in. No. 3	A	18·2	28·4	28·0	38
	B	17·2	28·6	28·0	38
1¼ in.	A	17·7	27·6	29·0	39
	B	18·0	27·5	28·0	38

Table IV

Chemical analysis and mechanical properties of BS.2762 plate material

	Steel ND I	*Steel ND IV*
Carbon, %	0·16	0·135
Silicon	0·023	0·16
Sulphur	0·045	0·041
Phosphorus	0·034	0·022
Manganese	1·05	1·04
Nickel	0·050	0·08
Chromium	0·025	0·07
Molybdenum	Nil	0·015
Copper	0·065	0·12
Tin	0·002	0·027
Arsenic	0·051	—
0·2% proof stress, tons/sq.in. (yield point)	18·5	19·0
U.T.S., tons/sq.in.	28·4	29·0
Elong., %	38	40
Red. in area, %	—	68

Table III

Mechanical properties of BS.15 plate material
(Results of check tests on material in various conditions)

Plate and Condition	*No. of Tests*	*Yield Stress tons/sq.in.*	*U.T.S. tons/sq.in.*	*Elong. on $4\sqrt{A}$, %*	*Red. in Area, %*
½ in., as received	3	17·57	29·2	36	50·5
½ in., stress relieved	14	17·49	28·35	43·3	65·7
½ in., improperly stress relieved	3	15·1	25·2	42	55·5
1¼ in., stress relieved	10	18·63	27·4	39·4	61·7

Table V

Details of test groups

Series	*Plate Thickness, in.*	*Material and Joint Type*	*Joint No. (see Figs. 6 and 7)*	*Stress Relieved*	*Remarks*
Plain plate specimens					
PN 1	½	BS.15 plate	—	No	Mill scale removed
PN 2	½	,, ,,	—	No	Mill scale on
PX	½	,, ,,	—	Incorrectly	,, ,, ,,
PS	1¼	,, ,,	—	Yes	,, ,, ,,
PN 3	1	ND I plate	—	No	,, ,, ,,
PN 4	1	ND IV plate	—	No	,, ,, ,,
Manually welded transverse butt joints in BS.15 plate					
MNG 1	½	Single **V**: E319 electrodes	1	No	Machine gas-cut preparation
MNH 1	½	,, ,,	1	No	Hand gas-cut preparation
MN 1	½	,, ,,	1	No	—
MS 1	½	,, ,,	1	Yes	—
MNR 1	½	,, ,,	1	No	Reinforcement removed
MSR 1	½	,, ,,	1	Yes	Reinforcement removed
MS 1	½	,, ,,	1	Incorrectly	—
MS 3	½	Close square butt E439 D.P. electrodes	3	Incorrectly	—
MX 5	1¼	Single **U**; E319 electrodes	5	Incorrectly	—
Automatically welded transverse butt joints in BS.15 (submerged-arc)					
AS 2	½	Single **V** butt	2	Yes	—
AS 4	½	Close square butt	4	Yes	—
ASR 2	½	Single **V** butt	2	Yes	Reinforcement removed
ASR 4	½	Close square butt	4	Yes	Reinforcement removed
AS 7	½	Double **V** butt	7	Yes	—
AS 6	1¼	,, ,, ,,	6	Yes	—

Building Construction). All plates were rolled from the same cast, which was a basic open-hearth, semi-killed (balanced) steel without aluminium addition. Rolling was carried out from an upper temperature of 1280°C. to a finishing temperature of approx. 920°C. The chemical analysis and mechanical properties of the material, as reported by the steelmaker, are given in Tables I and II. The ultimate tensile stress for the 1¼ in. plate falls slightly below the minimum of 28 tons/sq.in. specified by BS.15. In Table III are recorded the mechanical properties obtained by check tests on the material in various conditions.

The 1 in. thick notch ductile steels complied with BS.2762:1956. The ND I grade was a semi-killed mild steel of high Mn/C ratio by comparison with the BS.15 plate. The ND IV grade was a low carbon, high manganese, aluminium killed, grain controlled steel, normalized at 900°–920°C. Chemical analyses and mechanical properties of the two steels are given in Table IV. The fatigue tests on both grades were carried out with the steel in the as-received condition.

Specimen form and manufacture

The results of tests on twenty-one series of specimens are outlined in this report, and the characteristics of the various groups are shown in Table V. Except where otherwise stated, the mill scale was not removed and on welded specimens the reinforcement was retained. All specimens were manufactured so that in fatigue testing the stress was in the direction of rolling of the plate.

Nomenclature

The general details of most specimens can be determined from the identification letters in Table V, as follows:

P = plain plate
M = manual butt weld
A = submerged-arc automatic butt weld
N = not stress relieved
S = stress relieved
X = incorrectly stress relieved
G = machine gas-cut weld preparation
H = hand gas-cut weld preparation
R = weld reinforcement removed.

For the welded groups the number following the letter refers to the joint type shown in Tables VI and VII.

Table VI

Details of manually welded joints

Joint No.	*Type*	*Form*	*Electrode*	*Current*	*Electrode Size s.w.g.*		
					First Run	*Subsequent Runs*	*Sealing Run*
1	Single V butt	½ in. plate, 60° V, with $\frac{1}{16}$ in. root face; $\frac{5}{32}$ in. gap (no gap for MX 1)	E319	a.c.	8	8 and 6	8
					For Group MXI only		
					10	4 and 6	6
3	Close square butt	½ in. plate	E439 Deep Penetration	300 amp a.c.	6	—	6
					Welding speed = 14 in./min		
5	Single U butt	1½ in. plate, 10° included angle with ⅜ in. radius at root; $\frac{1}{16}$ in. root face, no gap	E319		4	4	6

Table VII

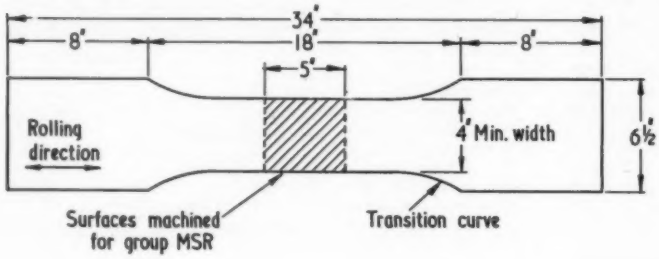
Automatically welded joints: submerged-arc

Joint No.	*Type*	*Form*	*Welding Order*	*Current, amp*	*Voltage, V*	*Welding Speed, in./min*	*Dia. of Electrode, in.*
2	Single V butt	½ in. plate, 90° V; $\frac{3}{16}$ in. root face, no gap	1st side A (using copper backing bar	600	40	6½	¼
			2nd side B	760	40	11	¼
4	Close square butt	½ in. plate	1st side A	720	34–36	12	¼
			2nd side B	880	38–40	14	¼
6	Double V butt	1½ in. plate, 60° V, ½ in. deep, side A; 70° V, ⅜ in. deep, side B; no gap	1st side A	1150	42–44	12	¼
			2nd side B	1300	42	10	$\frac{5}{16}$
7	Double V butt	½ in. plate, 90° V, $\frac{1}{16}$ in. deep both sides; no gap	1st side A	600	30	24	$\frac{5}{16}$
			2nd side B	625	30	24	$\frac{5}{16}$

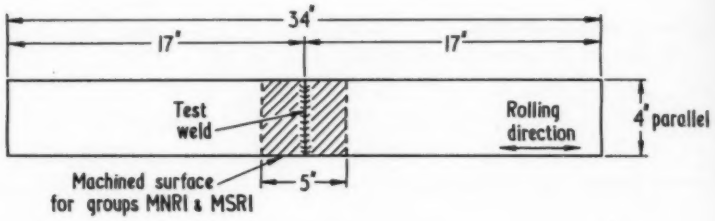
Plain plate specimens

The form of specimen used for the tests on plain plates is shown in Fig. 1. The specimens were tested with mill scale on, except those in series PN 1 which had the scale removed by longitudinal planing followed by hand draw-filing in the same direction. Approximately 0·040 in. was removed from each surface.

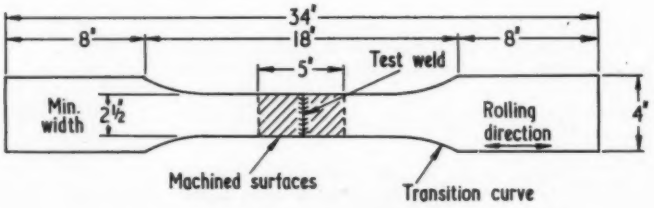
As shown in Fig. 1 the plain plate specimens were made with a transition curve of the Thum and Bautz type[1] between the test section and enlarged ends. Without facilities for profile milling these curves were machined in a centre lathe, the specimens being rotated about their longitudinal axes with the cutting tool cross-slide following a template attached to the lathe bed. In section, therefore, the two machined



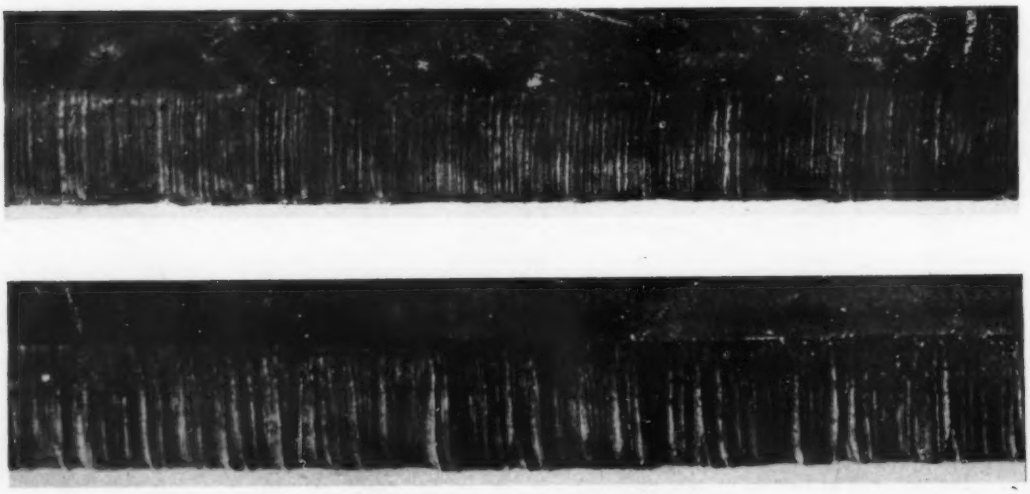
1—*Dimensions of plain plate specimens and specimens MSR 1\|2, 5, 8*



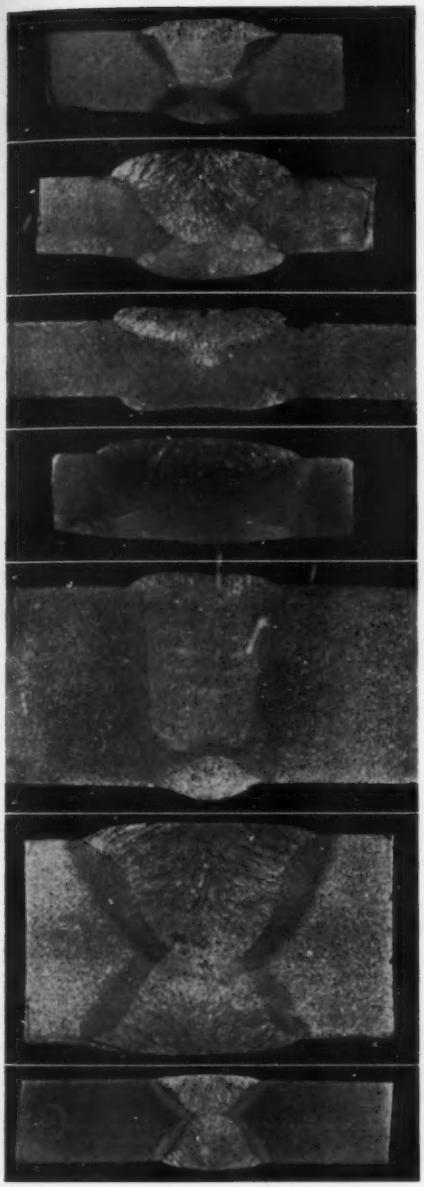
2—*Dimensions of welded specimens (except Groups ASR2 and ASR4, and specimens MSR 1\|2, 5, 8)*



3—*Dimensions of specimens in Groups ASR2 and ASR4*



4—*Typical gas-cut surfaces for weld preparations: (a) Machine gas cut as for series MNG 1; (b) hand gas cut as for series MNH 1*



(1) ½ in. single-V butt, manual weld
(2) ½ in. single-V butt, automatic weld
(3) ½ in. close square butt, manual weld
(4) ½ in. double-V butt, automatic weld
(5) 1¼ in. single-U butt, manual weld
(6) 1¼ in. double-V butt, automatic weld
(7) ½ in. close square butt, automatic weld

5—Macrosections of joints type 1–7 ×1

edges were of circular form. After machining in this way the section corners were finished by hand to a radius of $\frac{1}{16}$ in.

The efficacy of this plain plate design was well proved for most of the test series, but the results for series PN 1 were not entirely satisfactory in respect of mode of failure (see p. 576).

Series PS was stress relieved by treatment at 650°C. for 1 hr per inch of thickness. Series PX was also stress relieved, but it was discovered that this had been done incorrectly, with consequent decarburization of the surface. None of the other groups was stress relieved.

Welded specimens

Details of the various joint preparations and welding conditions used in the construction of the BS.15 welded specimens are shown in Tables VI and VII, and macrosections cut from each joint type are shown in Fig. 5.

For most of the test groups the general form of specimen consisted simply of a 4 in. wide parallel strip, with the weld made transversely at the centre of the specimen length, as shown in Fig. 2. However, this form of test piece was found to be less suitable for those groups which had the weld reinforcement removed, so that for series ASR 2 and ASR 4 the form of test piece shown in Fig. 3 was used. Series MNR 1, however, and some of the specimens in series MSR 1, did conform to the specimen shape shown in Fig. 2, the remainder of the specimens in series MSR 1 (*i.e.*, MSR 1/2, MSR 1/5, and MSR 1/8) being as shown in Fig. 1.

Except for series MNG 1 and MNH 1 the specimens were prepared for welding by machining. Series MNG 1 were machine gas-cut (oxy-acetylene) and series MNH 1 were hand gas-cut (oxy-acetylene). In both these cases an attempt was made to reproduce a surface finish equivalent to that of good commercial practice; typical examples are shown in Fig. 4. The actual details of the procedure are shown in Table VIII. The root face was made by filing after the cutting had been completed.

Table VIII

Details of gas cutting

	Machine Cutting (Series MNG 1)	*Hand Cutting (Series MNH 1)*
Cutting nozzle, dia., in.	$\frac{1}{16}$	$\frac{1}{16}$
Oxygen pressure (heating), lb/sq.in.	30	30
Oxygen pressure (cutting), lb/sq.in.	35	35
Acetylene pressure, lb/sq.in.	2	2
Speed of cutting, in./min	12	8

In welding, care was taken to ensure full penetration. The manually welded joints made with E.319 electrodes were back chipped before depositing the sealing run. Undercutting was avoided and accurate alignment of the plates was maintained.

Specimens in series MS 1, MSR 1, AS 2, AS 4, ASR 2, ASR 4, AS 6 and AS 7, were stress relieved at 650°C. for 1 hr per inch of thickness. Those in series MX 1, MX 3 and MX 5 were incorrectly stress relieved and this resulted in the formation of a decarburized layer at the surface. The other specimens were not stress relieved.

Radiography

Some of the test groups were examined by the X-ray method before fatigue testing, and porosity was usually found in the manually welded joints. There is some difficulty in expressing the porosity severity for these welds, but the worst conditions were estimated to be:

(*a*) In $\frac{1}{2}$ in. welds: five $\frac{1}{32}$ in. dia. pores per inch, occurring substantially as a single line of pores in the root area
(*b*) In $1\frac{1}{4}$ in. welds: thirty $\frac{1}{64}$ in. dia. pores per sq.in. (measured on X-ray film) uniformly scattered across the width of the radiographic image.

These defects had no effect on the fatigue behaviour of the test specimens, failure occurring consistently from the edge of the reinforcement. An exception to this general rule occurred in series MX 3, welded with deep-penetration electrodes, in which a somewhat higher degree of porosity severity prevailed. In these specimens the indicated pore size varied up to approx. $\frac{3}{32}$ in. dia. maximum; a typical radiograph is shown in Fig. 6. In two specimens of this group porosity did lead to failure, but only after cracks had also developed at the edge of the weld reinforcement (see p. 585).

6—Typical porosity in manual deep-penetration welds (specimen MX 3)

Method of Testing

All the specimens, except those in series ASR 2 and ASR 4, were tested in a 100 tons hydraulic machine at a testing frequency in the range 200–400 c/min. The accuracy of this machine was determined by calibration tests to be within $\pm 0{\cdot}5\%$ of maximum load or $\pm 2\%$ of the actual load, whichever is the greater. Series ASR 2 and ASR 4 were tested in a 60 tons Schenck machine at a testing speed of 2000 c/min. In both cases the test loads were axial, with a pulsating tension load cycle having a lower limit of zero. To ensure that the use of a different machine for testing two of the groups would not introduce any error into the results, two of the specimens in series ASR 4, namely ASR 4/6 and ASR 4/8, were tested in the hydraulic machine; the resulting lives were almost identical to those of specimens ASR 4/5 and ASR 4/9, which were tested at the same stress level in the Schenck machine.

In setting up the specimens particular care was taken to reduce, as far as possible, bending about the major axis of the section, so as to avoid failures from the edge or corner of the cross section. This was comparatively simple since major axis bending was found to be a function of the accuracy of setting up. Bending about the minor axis, however, was found to be a function of the accuracy of manufacture of the specimens (*i.e.*, their straightness). Electric resistance strain gauges and mechanical extensometers were used to facilitate setting up, and the operation could usually be completed fairly quickly. With the hydraulic machine the setting-up operation was aided by the use of special attachments fitted across the sides of the machine grips, which permitted accurate and controlled adjustment of the position of the specimens relative to the grips. (For details see Appendix and Figs. 28–30).

The testing procedure for each group of specimens was intended to establish S/N curves for a range of

7—Fatigue crack revealed after static test

endurance values from approximately 100,000 cycles to a maximum of 2,000,000 cycles, the fatigue strength at 2×10^6 cycles being accepted as a criterion of performance. This fatigue strength value was to be defined by the upper limit tension stress for which at least two specimens were unbroken at 2×10^6 cycles. Following a recommended procedure[2] adopted by Commission XIII (Fatigue Testing) of the International Institute of Welding, any specimen surviving 2×10^6 cycles was afterwards tested statically to failure to confirm that no fatigue cracks, at least of macroscopic dimensions, were present. Where fatigue cracks were found in this way (a typical example is shown in Fig. 7), the specimen concerned was considered to have failed, and additional tests were carried out at slightly lower stress levels in an attempt to satisfy the stated conditions.

For those specimens failing at some earlier stage of endurance, life was determined either by complete rupture of the specimen or by drop-of-load consequent upon the plastic extension or 'necking' of residual areas adjacent to the propagating fatigue crack. It was noticeable that the latter feature usually applied to plain plate specimens, in which cracks were often initiated near the centre of width.

Results and Discussion of Tests

It is convenient to consider the results of the various tests by dividing the complete test programme into sections corresponding to the various factors investigated:

(1) Influence of mill scale and plate thickness on the fatigue strength of plain plate
(2) Fatigue strength of notch ductile steels
(3) Influence of the method of edge preparation for welding
(4) Influence of stress relief after welding
(5) Influence of improper stress relief, which produced a decarburized surface layer
(6) Effect of weld reinforcement shape
(7) Fatigue strength of welds in 1¼ in. thick BS.15 mild steel.

Table IX

Summary of results for series PN 1
(½ in. plain plate with machined surfaces, not stress relieved)

Specimen	*Upper Limit Stress, tons/sq.in.*	*Million Cycles to Failure*	*Remarks*
PN 1/1	22	0·229	Failed from edge
PN 1/2	20·6	1·034	Failed from surface
PN 1/3	20	0·456	Polished edge preparation. Failed from corner in transition curve
PN 1/4	20	0·559	Failed from edge in transition curve
PN 1/5	20	0·598	Failed from corner in transition curve
PN 1/6	20	0·778	Failed from corner
PN 1/7	20	0·937	Polished edge preparation. Failed from edge in transition curve
PN 1/8	19	1·886	Failed from corner in transition curve
PN 1/9	19	2·033	Unbroken. No fatigue cracks found in static test
PN 1/10	19	2·763	
PN 1/11	18	2·115	

Tests on plain plate

The results of the tests on the mild steel plain plate specimens (series PN 1, PN 2, PX, and PS) are set out in Tables IX–XII and the various S/N curves are shown in Fig. 8.

In the PN 2 series (Table X), which was tested with mill scale surfaces, six failures were obtained and two specimens remained unbroken after at least 2×10^6 cycles under a tensile stress range of 0–16 tons/sq.in., the absence of fatigue cracks being confirmed by static testing. Figure 9 shows a fracture typical of those obtained. The fractures were located in the test portion of the specimens, with the exception of PN 2/4, which failed in the area of the transition curve owing to the presence there of a fairly heavy score mark on the mill scale surface.

Table X

Summary of results for series PN 2
(½ in. plain plate as rolled, not stress relieved)

Specimen	*Upper Limit Stress, tons/sq.in.*	*Million Cycles to Failure*	*Remarks*
PN 2/1	20	0·224	Failed from surface defect in transition zone
PN 2/2	20	0·387	Failed in rolled surface and at corner of test section
PN 2/3	18	0·795	Failed from rolled surface in test section
PN 2/4	18	1·033	
PN 2/5	17	0·903	
PN 2/6	17	1·982	
PN 2/7	16	2·062	Fractured statically after fatigue test. No fatigue cracks observed
PN 2/8	16	2·824	

Table XI

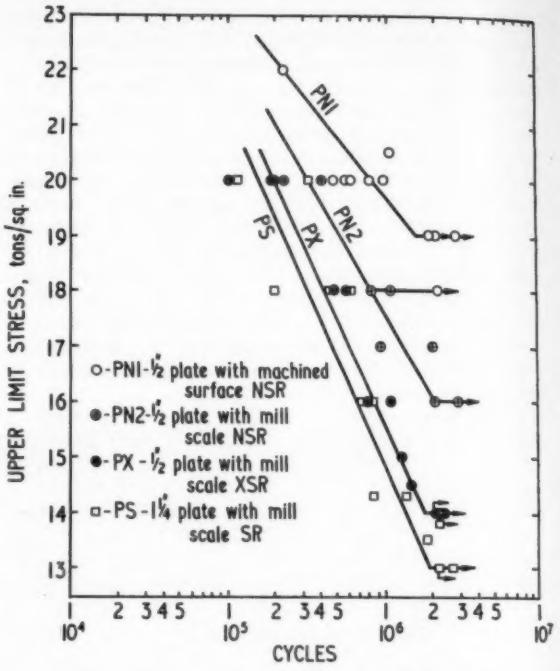
Summary of results for series PX
(½ in. plain plate with mill scale, improperly stress relieved)

Specimen	*Upper Limit Stress, tons/sq.in.*	*Million Cycles to Failure*	*Remarks*
PX/1	20	0·099	Failed from corner of section. Numerous fissures in rolled surface
PX/2	20	0·190	Fractured from rolled surface. Numerous fissures near main fracture
PX/3	20	0·199	Two major fractures from rolled surface. Numerous small cracks and fissures
PX/4	18	0·463	Fractured from corner of section
PX/5	18	0·559	
PX/6	16	0·753	Fractured near corner of section
PX/7	16	1·099	Fractured from rolled surface
PX/8	15	1·274	
PX/9	14·5	1·460	
PX/10	14	2·063	Unbroken. No fatigue cracks found in static test
PX/11	14	2·379	

Table XII

Summary of results for series PS
(1¼ in. plain plate with mill scale, stress relieved)

Specimen	*Upper Limit Stress, tons/sq.in.*	*Million Cycles to Failure*	*Remarks*
PS/1	20	0·113	Failed from defect in rolled surface. Numerous fissures in rolled surface
PS/2	20	0·316	Failed from corner of section. Numerous small fissures in plate surface
PS/3	18	0·194	Failed near corner of section from score mark
PS/4	18	0·457	Failed from rolled surface. Four small cracks near main fracture
PS/5	18	0·586	Failed from rolled surface. Small cracks near main fracture
PS/6	16	0·700	Fractured from rolled surface
PS/7	16	0·809	
PS/8	14·3	0·835	
PS/9	14·3	1·339	
PS/10	14	2·208	
PS/11	13·8	2·221	Unbroken. No fatigue cracks found in static test
PS/12	13·5	1·874	Failed from rolled surface
PS/13	13	2·183	Unbroken. No fatigue cracks found in static test
PS/14	13	2·645	
PS/15	21	0·502	Check tests on specimens with machined surfaces unbroken
PS/16	19	2·2	



8—*Fatigue test results for 1¼ in. and ½ in. thick BS.15 plate*

The tests on specimens of the PN 1 series with machined surfaces were, in general, characterized by failure in the transition zone (see Table IX). Of the eight fractures obtained only three were located in the test portion, and of these one was initiated at the edge and another at the corner of the section. The remaining one of the three, specimen PN 2/2, failed in a similar manner to that shown in Fig. 8.

Of the three specimens in this series that were unbroken after 2×10^6 cycles, one had been tested under a stress range of 0–18 tons/sq.in. and the two others at 0–19 tons/sq.in. A third specimen PN 1/8, however, when tested under the latter stress, failed at $1{\cdot}8\times10^6$ cycles in the transition zone. With the data available it is not possible to assert that a significant

(a)

(b)

9—*Failure of PN 2 specimen (½ in. BS.15 plain plate with mill scale): (a) Fracture at conclusion of test, pulled open owing to plastic deformation of ligaments; (b) fracture surfaces*

loss of life is associated with failure in this area, but the fact that so many specimens failed there suggests it. In view of this, and considering that specimen PN 1/8 had endured very nearly 2×10^6 cycles under 0–19 tons/sq.in. before failing in the transition zone, it is reasonable to take this value, which is supported by two other tests, as the control value for this number of cycles. An attempt was made to secure further results for the desired mode of failure by polishing the areas around the transition curves on two specimens tested at 0–20 tons/sq.in. Although one of these, PN 1/7, gave the highest life for the 20 tons/sq.in. stress level, failure in each case remained in the transition zone.

The third series, PX, of $\frac{1}{2}$ in. thick mild steel specimens had been stress relieved, although it was later discovered that this had not been carried out correctly so that a decarburized layer approximately $\frac{1}{16}$ in. thick existed on the surface. (A full discussion of this effect is given later.) Nine fractures were obtained, most being initiated at the rolled surface, and two specimens survived 2×10^6 cycles under a stress range of 0–14 tons/sq.in. The full results for this series are given in Table XI.

The $1\frac{1}{4}$ in. thick mild steel plate series PS was tested in the stress relieved condition, and the results are shown in Table XII. Eleven fractures were obtained, most of them being initiated at the rolled surface, in some cases starting from slight imperfections such as small surface pits or light score marks. Two failures, PS/2 and PS/3, were initiated at the corner of the section, but all the failures occurred within the test length between the transition zones. Three specimens were unbroken after 2×10^6 cycles, one having been subjected to a stress range of 0–13·8 tons/sq.in. and the other two to 0–13 tons/sq.in. As a specimen tested at 0–13·5 tons/sq.in. failed before reaching this life, the fatigue strength has been taken as 13 tons/sq.in. This value is about 80% of the strength of $\frac{1}{2}$ in. plain plate (series PN 2) and since there is at the most a 5% difference between the ultimate tensile strengths of the two thicknesses, the reduction must be attributed primarily to the rougher surface condition of the less heavily rolled $1\frac{1}{4}$ in. plate. Two check tests on $1\frac{1}{4}$ in. plain plate specimens with machined surfaces were carried out to provide a more adequate demonstration of the influence of this rougher surface. The specimens, PS/15 and PS/16, were tested at 0–21 and 0–19 tons/sq.in. respectively and gave lives fully equivalent to those of the $\frac{1}{2}$ in. specimens with machined surfaces, series PN 1; specimen PS/16 was, in fact, unbroken after 2×10^6 cycles at 0–19 tons/sq.in., the accepted fatigue strength of series PN 1. The results of these check tests are included in Table XII.

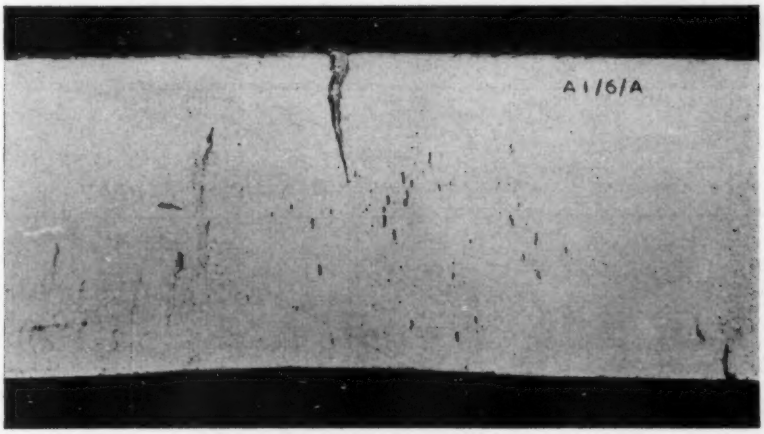
In both series PN 2 and PS an interesting feature was the development of numerous smaller cracks in the rolled surfaces of specimens subjected to upper limit stresses at or above the initial yield value. These cracks were usually congregated in the area of the major fatigue crack and appeared to be confined to the $\frac{1}{2}$ in. thick plates tested at 0–20 tons/sq.in. and the $1\frac{1}{4}$ in. plates tested at or above 0–18 tons/sq. in. Figure 10 shows a typical specimen which failed in this manner.

Table XIII

Comparison of test results for BS.15 plain plate

Series	*Upper Limit Stress at 2×10^6 cycles, tons/sq.in.*	*Strength as percentage of Series PN 2*
PN 2—$\frac{1}{2}$ in plain plate with mill scale	16	100
PN 1—$\frac{1}{2}$ in. plain plate with machined surfaces	19	119
PX —$\frac{1}{2}$ in. plain plate with mill scale, and improperly stress relieved	14	87·5
PS —$1\frac{1}{4}$ in. plain plate with mill scale, stress relieved	13	81·2

Thus, the results of the tests on plain plate specimens in mild steel to BS.15 may be summarized as shown in Table XIII. The PN 2 series of $\frac{1}{2}$ in. plate tested with mill scale on is used as the basic control value of fatigue strength, and the strength of the other groups is expressed as a percentage of this value.



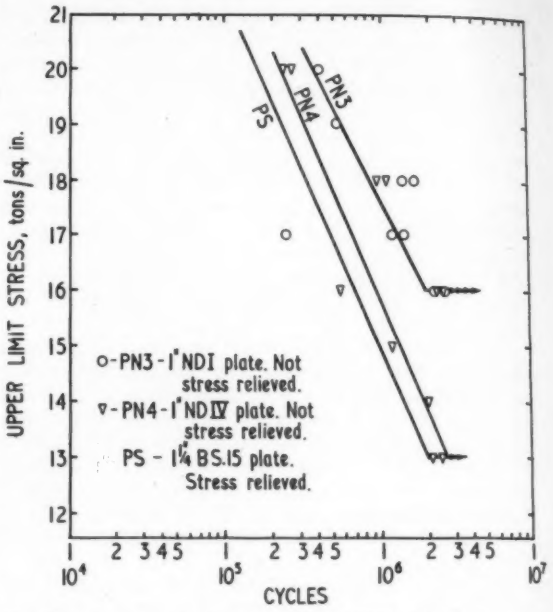
10—*Multiple fatigue cracking in BS.15 plain plate specimen*

Tests on notch ductile steel

Some check tests on two grades of 1 in. thick notch ductile steel, ND 1 (series PN 3) and ND IV (series PN 4) were carried out on plain plate specimens only. These were planned so as to compare fatigue strengths with BS.15 plate and, in particular, to observe the behaviour of the aluminium-killed ND IV grade. Both series of specimens were tested with the mill scale left on. The results are set out in Tables XIV and XV and are shown in the form of S/N curves in Fig. 11.

In general, failure was initiated at the rolled surface in both series, although in one specimen, PN 3/2, failure started from an extensometer indentation on the rolled surface and in another, PN 4/3, failure was initiated at a corner of the specimen.

The ND I specimens suffered some scattering in fatigue results, which appeared to be related to surface condition but indicated a strength of 0–16 tons/sq.in. at 2×10^6 cycles; equivalent to the strength of $\frac{1}{2}$ in. BS.15 plate. Somewhat greater scattering was obtained with the ND IV specimens, of which two were unbroken at 2×10^6 cycles under a stress range of 0–16 tons/sq.in. whereas two more failed between 1 and 2 million cycles at lower stresses; a lower limit strength of 0–13 tons/sq.in. was established in two further tests. This variation was more clearly related to surface condition, and the upper limit of 0–16 tons/sq.in. may be taken to represent the strength of


UPPER LIMIT STRESS, tons/sq. in.
CYCLES
PN3
PN4
PS
o-PN3 - 1" ND I plate. Not stress relieved.
▽-PN4 - 1" ND IV plate. Not stress relieved.
PS - 1¼ BS.15 plate. Stress relieved.

11—*Fatigue test results for 1 in. thick BS.2762 plain plate*

Table XIV

Summary of results for series PN 3
(1 in. plain plate ND 1 with mill scale, not stress relieved)

Specimen	*Upper Limit Stress, tons/sq.in.*	*Million Cycles to Failure*	*Remarks*
PN 3/1	20	0·391	Failed from rolled surface
PN 3/2	19	0·509	Failed from indentation caused by mechanical extensometer
PN 3/3	18	1·342	Failed from rolled surface
PN 3/4	18	1·601	
PN 3/5	17	0·247	
PN 3/6	17	1·152	
PN 3/7	17	1·362	
PN 3/8	16	2·131	Unbroken. No fatigue cracks found in static test
PN 3/9	16	2·466	

Table XV

Summary of results for series PN 4
(1 in. plain plate ND IV with mill scale, not stress relieved)

Specimen	*Upper Limit Stress, tons/sq.in.*	*Million Cycles to Failure*	*Remarks*
PN 4/1	20	0·239	Multitudinous cracking from rolled surface
PN 4/2	20	0·266	
PN 4/3	18	0·935	Failed from corner of section
PN 4/4	18	1·065	Failed from rolled surface
PN 4/5	16	0·542	
PN 4/6	16	2·176	Unbroken. No fatigue cracks detected after static test
PN 4/7	16	2·274	
PN 4/8	15	1·148	Failed from rolled surface
PN 4/9	14	1·961	
PN 4/10	13	2·021	Unbroken. No fatigue cracks detected after static test
PN 4/11	13	2·393	

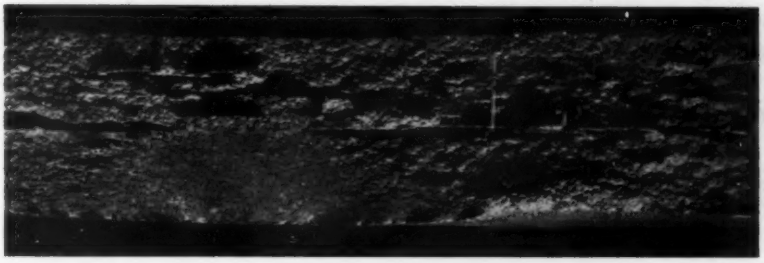
Table XVI

Comparison of mechanical properties of BS.15 and BS.2762 plain plate

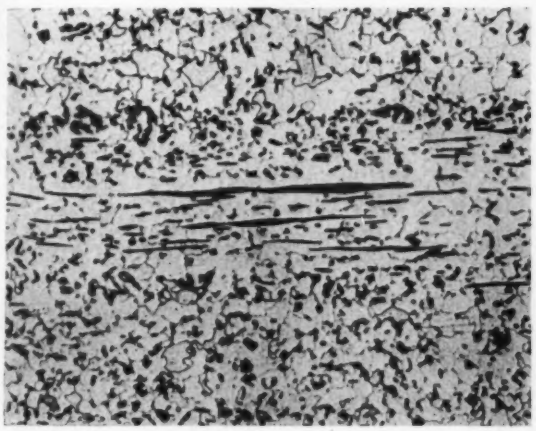
Series	*Yield Stress, tons/sq.in.*	*U.T.S., tons/sq.in.*	*Elong. on $4\sqrt{A}$, %*	*Upper Limit Stress at 2×10^6 Cycles, tons/sq.in.*	*Strength as Percentage of Series PN 2*
PN 2 ½ in. BS.15 plain plate with mill scale	17·5	29·2	36	16	100
PS 1¼ in. BS.15 plain plate with mill scale, stress relieved	18·0	27·5	38	13	81·2
PN 3 1 in. ND 1, with mill scale	18·5	28·4	38	16	100
PN 4 1 in. ND IV, with mill scale	19·0	29·0	40	16	100

ND IV with reasonably smooth mill scale surfaces, whilst the lower value of 0–13 tons/sq.in. applies to specimens with pitting or score marks on the surface. For the purpose of comparison with ND I and BS.15 the upper limit is the more significant; a comparison of this kind is given in Table XVI.

Throughout the tests on the ND IV specimens fracture was initiated from the surface (including here the single case of failure from a corner), as mentioned above. The fracture surfaces contained a number of fissures lying in the direction parallel to the rolled surfaces and mainly congregated in the centre of thickness, as shown in Fig. 12. In one or two specimens it appeared that the advancing fatigue crack had been arrested at a fissure position and re-initiated on a different plane, giving rise to a stepped fracture surface. A macro-section taken through the full thickness of one of the specimens revealed the presence of elongated manganese sulphide inclusions in the regions of mid-thickness, these being contained in a central band of primary ferrite (Fig. 13). Further examination suggested that the fissures were actually caused by the opening up of the inclusions, but no evidence was found to indicate that the first initiation of a fatigue crack occured elsewhere than at the outer surface of the specimen.



12—*Fracture of notch-ductile plate specimen, series PN 4 (ND IV) grade steel*



13—*Inclusions in centre of thickness of ND IV plate* ×200

Table XVII

Summary of results for series MNG1
(½ in. manual butt welds with machine gas-cut edge preparation)

Specimen	*Upper Limit Stress, tons/sq.in.*	*Million Cycles to Failure*	*Remarks*
MNG 1/1	17	0·163	Failure from edge of weld reinforcement
MNG 1/2	15	0·485	
MNG 1/3	13	0·681	
MNG 1/4	12	1·877	
MNG 1/5	11·5	1·690	
MNG 1/6	11·5	2·162	Fatigue crack found in static test
MNG 1/7	11	1·572	Failure from edge of weld reinforcement
MNG 1/8	11	2·134	Unbroken. Fractured statically after fatigue test but no fatigue cracks observed
MNG 1/9	10	2·116	
MNG 1/10	10	2·393	

Effect of edge preparation

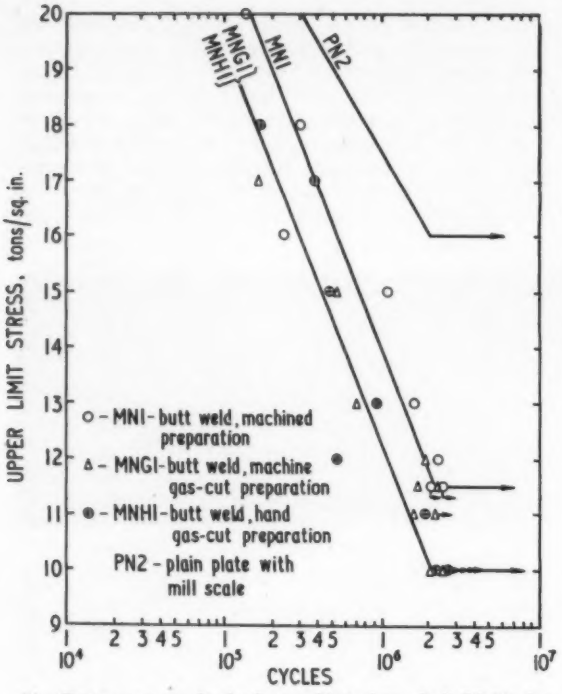
In this group two series of manually butt welded specimens in ½ in. thick BS. 15 plate were tested for comparison with series MN 1 welds with machined preparations. These were series MNH 1 with hand gas-cut preparations, and series MNG 1, which were machine gas-cut. The results of the fatigue tests are summarized in Tables XVII–XVIII and shown graphically in the S/N diagram (Fig. 14).

Throughout the tests the failures obtained were of the expected type for good quality welds, the fractures being initiated at one or more edges of the weld reinforcement. An example from series MN 1 is shown in Fig. 15. The group of specimens MNH 1 with hand gas-cut preparations were distinguishable, however, by

Table XVIII

Summary of results for series MNH 1
(½ in. manual butt welds with hand gas-cut edge preparation)

Specimen	*Upper Limit Stress, tons/sq.in.*	*Million Cycles to Failure*	*Remarks*
MNH 1/1	18	0·163	Failed from edge of weld reinforcement. Multiple cracking observed
MNH 1/2	17	0·386	
MNH 1/3	15	0·474	
MNH 1/4	13	0·916	
MNH 1/5	12	0·517	
MNH 1/6	11	1·884	
MNH 1/7	10	2·298	Unbroken. Fractured statically after fatigue test. No fatigue cracks observed
MNH 1/8	10	2·357	


UPPER LIMIT STRESS, tons/sq. in.
CYCLES
MNG1
MNH1
MN1
PN2
○ - MN1 - butt weld, machined preparation
△ - MNG1 - butt weld, machine gas-cut preparation
● - MNH1 - butt weld, hand gas-cut preparation
PN2 - plain plate with mill scale

14—*Fatigue test results for butt welds in ½ in. thick BS.15 plate with various edge preparations*

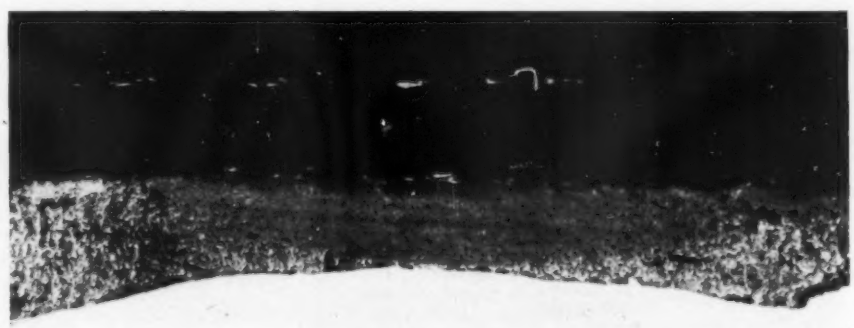
the development of several fatigue cracks. The multiple initiation of cracks has been observed to occur quite generally in plain plates tested above the initial yield stress of the material and there is a similar known tendency in welded specimens. In the series MNH 1, multiple cracking occurred at all stress levels between 11 and 18 tons/sq.in. and several points of initiation could often be seen in the final fracture surface, as indicated in Fig. 16.

For both the gas-cut series of specimens the established upper limit stress for an endurance of 2×10^6 cycles was 10 tons/sq.in. (Table XIX). This is approximately 13% below the corresponding stress for specimens with machined edge preparations. To some extent this difference is more apparent than real, particularly for the MNG 1 series in which the fairly

Table XIX

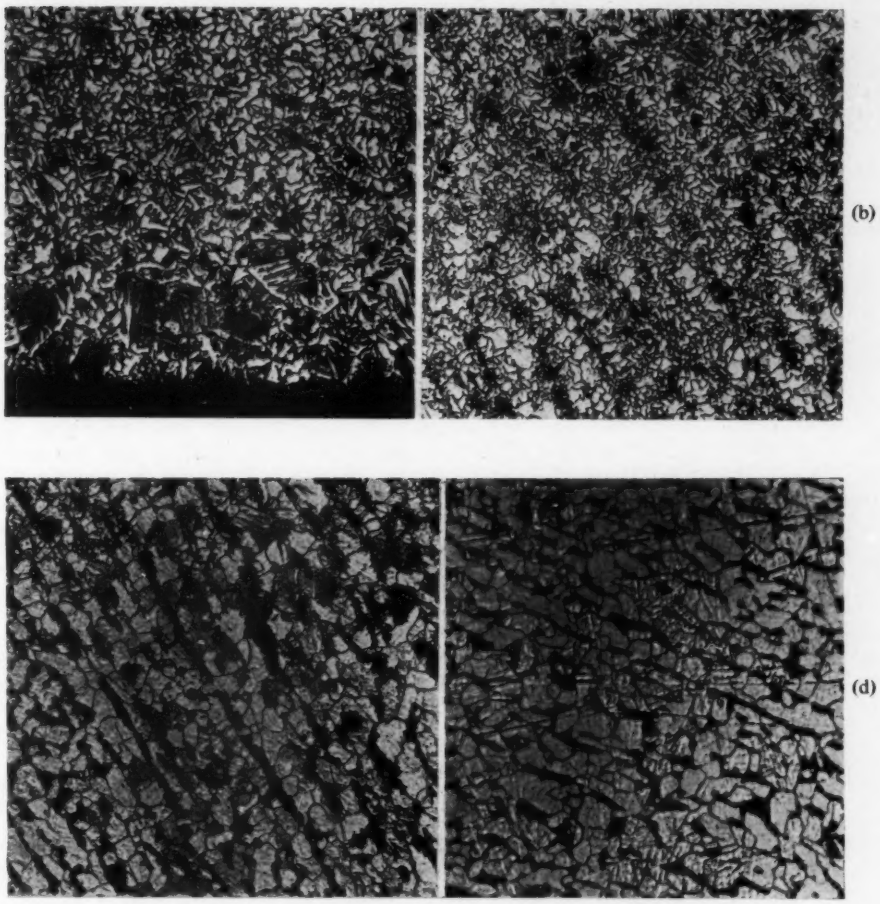
Comparison of test results for various edge preparations

	Series	*Upper Limit Stress at 2×10^6 cycles, tons/sq.in.*	*Strength as percentage of Series PN 2*
PN 2	½ in. plain plate with mill scale	16	100
MN 1	½ in. butt joint, machined edge preparation	11·5	71·9
MNG 1	½ in. butt joint, machine gas-cut edge preparation	10	62·5
MNH 1	½ in. butt joint, hand gas-cut edge preparation	10	62·5



15—*Fatigue fracture at edge of reinforcement in series MN 1 specimen (manual butt weld in ½ in. BS.15 plate)*

16—*Multiple initiation of fatigue cracks at edge of reinforcement in series MNH 1 specimen (manual butt weld in ½ in. BS.15 plate; hand gas-cut weld preparation)*



17—*Micro-structures in heat-affected zone of gas-cut surface. Etched 30 sec., 2% nital* ×130
(a) At gas-cut surface; (b) intermediate between (a) and (c); (c) adjacent to unaffected parent plate; (d) unaffected parent plate

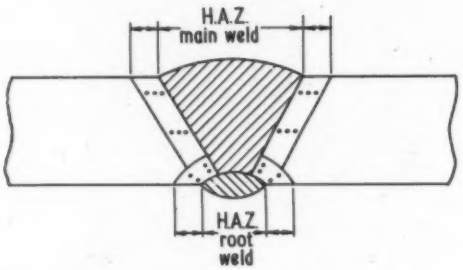
small stress adjustments made at the lower end of the S/N curve corresponded to about the limit of accuracy of load measurement, but an examination of the gas-cut specimens was carried out to determine whether any metallurgical features arising from the cutting operation remained after welding.

To obtain an impression of the initial effects of gas cutting, two surfaces, one cut by hand and one by machine, were examined. In each case three areas in the heat-affected zone could be distinguished. These are shown in Fig. 17. The first area (*a*) existed at the cut surface and had the appearance of a typical Widmanstätten structure with sorbitic pearlite in fairly large, well-defined grains. The adjacent area (*b*) had smaller pearlite grains of fine structure, and the final zone (*c*), running into the unaffected parent metal, contained medium size patches of fine pearlite between ferrite grains, the structure having the appearance of material just heated to the first critical temperature. It was noticeable that in the hand gas-cut specimen these three zones were more irregular and less sharply defined than in the machine gas-cut specimen.

Transverse sections cut from one of the welded joints in each series were then examined, with particular reference to the heat-affected zone, so as to identify any residual effects of gas cutting. The principal point of interest, therefore, was to compare the MN 1 weld with those in the MNG 1 and MNH 1 gas-cut specimens. In their general metallurgical appearance the heat-affected zones were similar, those from the gas-cut specimens revealing no important modification that could be related to the pre-weld cutting operations. Hardness tests on these zones likewise did not show any significant differences, as illustrated in Fig. 18. By comparison, the root weld heat-affected zone of MNG 1 specimens can probably be accounted as of a slightly different order of hardness, but this could be attributed to a variation of root weld size noted in the macro-sections.

From the evidence available therefore, the reduction of strength cannot be clearly associated with the use

of gas cutting, and it is more likely that a variation of reinforcement shape, later measured on selected specimens (see p. 588), was the cause both of strength differences between groups and the multiple initiation of cracks in given specimens.



18—*Hardness of heat-affected zones for specimens from series MN 1, MNH 1, MNG 1 (10 kg load)*

Series	*Main Weld*	*Root Weld*
MN 1	160–177	177–215
MNH 1	148–160	178–201
MNG 1	163–181	194–228

Table XX

Summary of results for series MN 1
(½ in. manual butt weld with machined edge preparation, not stress relieved)

Specimen	*Upper Limit Stress, tons/sq.in.*	*Million Cycles to Failure*	*Remarks*
MN 1/1	20	0·139	Failure from edge of weld reinforcement
MN1/2	18	0·296	Failure from edge of weld reinforcement at specimen edge
MN 1/3	16	0·236	
MN 1/4	15	1·014	Failure from edge of weld reinforcement
MN 1/5	13	1·594	Failure from edge of weld reinforcement at specimen edge
MN 1/6	12	2·210	Failure at edge of reinforcement discovered in static test
MN 1/7	11·5	2·139	Unbroken. Fractured statically after fatigue test. No cracks found
MN 1/8	11·5	2·406	

Table XXI

Summary of results for series MS 1
(½ in. manual butt weld, stress relieved)

Specimen	*Upper Limit Stress, tons/sq.in.*	*Million Cycles to Failure*	*Remarks*
MS 1/1	18	0·191	Failed from edge of weld reinforcement
MS 1/2	16	0·574	
MS 1/3	15	0·526	
MS 1/4	14	0·676	
MS 1/5	13	0·957	
MS 1/6	11·5	1·325	
MS 1/7	11·5	2·359	Unbroken. No fatigue cracks found in static test
MS 1/8	11·5	2·500	

Effect of Stress Relief

To determine whether the application of a 650°C stress-relieving treatment would have any influence on the fatigue strength of the butt welded specimens, tests were carried out to compare four series of ½ in. specimens:

(i) MS 1—manually welded, reinforcement on, stress relieved

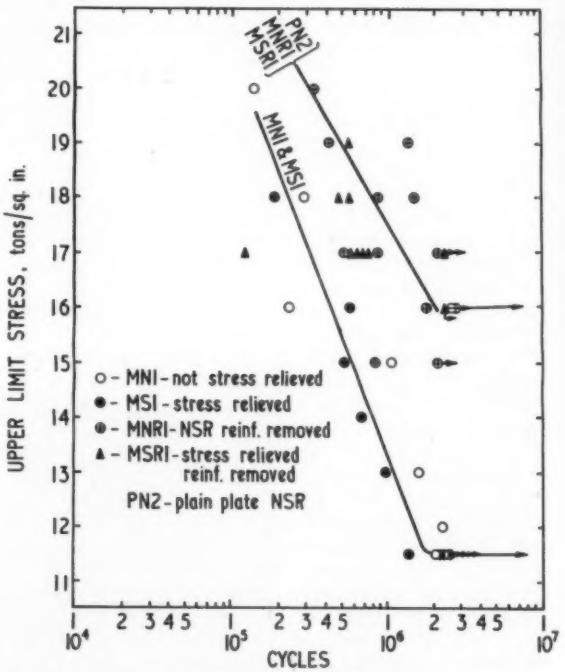
(ii) MN 1—manually welded, reinforcement on, not stress relieved.

(iii) MSR 1—manually welded, reinforcement removed, stress relieved

(iv) MNR 1—manually welded, reinforcement removed, not stress relieved.

The tests on series MN 1 have been described in the previous section dealing with the method of edge preparation, and the results are set out in Table XX. The results for series MS 1 are given in Table XXI, from which it will be seen that all failures were initiated at the edge of the reinforcement. The two specimens which survived 2×10^6 cycles had each been subjected to a stress range of 0–11·5 tons/sq.in., and although one specimen, MS 1/6, failed at $1{\cdot}3\times10^6$ cycles under the same stress range it is not unreasonable to take 11·5 tons/sq.in. as the strength value common to both MN 1 and MS 1 groups, as indicated by the S/N diagrams (Fig. 19).

A considerable degree of scatter is shown in the results for series MNR 1 and MSR 1 (Tables XXII and XXIII) in which the specimens had the weld reinforcement removed. As previously noted a local



19—*Fatigue test results for ½ in. manual butt welds*

Table XXII

Summary of results for series MNR 1
(½ in. manual butt weld, reinforcement removed but not stress relieved)

Specimen	*Upper Limit Stress, tons/sq.in.*	*Million Cycles to Failure*	*Remarks*
MNR 1/1	20	0·339	Failed in machine grips
MNR 1/2	19	0·421	
MNR 1/3	19	1·328	Failure in weld
MNR 1/4	18	0·858	
MNR 1/5	18	1·465	Failure from surface pithole
MNR 1/6	17	0·552	Failure from weld defect
MNR 1/7	17	0·826	Failure from rolled surface
MNR 1/8	17	2·147	Unbroken
MNR 1/9	16	1·799	Failure in machine grips
MNR 1/10	16	2·374	Failure from rolled surface found under static load
MNR 1/11	16	2·536	Unbroken. No fatigue cracks found in static test
MNR 1/12	15	0·805	Failure from weld defect
MNR 1/13	15	2·111	Unbroken. No fatigue cracks found in static test

Table XXIII

Summary of results for series MSR 1
(½ in. manual butt weld, stress relieved and reinforcement removed)

Specimen	*Upper Limit Stress, tons/sq.in.*	*Million Cycles to Failure*	*Remarks*
MSR 1/1	19	0·554	Failed from machined surface
MSR 1/2	18	0·499	Failure from weld defect
MSR 1/3	18	0·569	Failed from surface at join of machined and mill scale surfaces
MSR 1/4	17	0·123	Failed from machined surface
MSR 1/5	17	0·559	Failure from edge in weld
MSR 1/6	17	0·606	Failure from extensometer mark
MSR 1/7	17	0·689	Failure from surface. Plate laminated
MSR 1/8	17	0·692	Failure from rolled surface
MSR 1/9	17	2·162	Unbroken. No fatigue cracks found in static test
MSR 1/10	16	2·339	

area of plate surface extending about 2½ in. on each side of the weld was machined to remove the reinforcement, this area being given a final hand polish. Also, for the MNR 1 series and some of the MSR 1 series, a parallel form of test piece was used. As the tests demonstrated, this kind of specimen suffers from the probability of failure occurring at any one of a number of points, including the gripped portion. Specimens with a reduced test section were later used to complete the MSR 1 series and in these grip failure was eliminated; even so, failures were then distributed between the mill scale surface, the machined surface away from the weld, the junction between these surfaces, and finally the weld itself.

The principal object in these tests was to compare the behaviour of 'as-welded' and stress relieved specimens, and it is clear that for specimens either with the reinforcement left on or removed stress-relieving has no significant effect. Table XXIV summarizes the general result. In this table it is also indicated that the removal of reinforcement by machining restores fatigue strength to the plain plate value. Firstly, it should be emphasized here that the machining was followed by hand polishing and re-emphasized that the material is a 0·18% C mild steel. These factors are of obvious importance in this context. Secondly, if the results are analysed in terms of strength and mode of failure it is clear that 100% restoration of strength depends upon an absence of weld defects and other 'artificial' stress concentrations, such as may exist at the grips and at the junction of machined and rolled surfaces. For example, while the same strength as plain plate is claimed, namely 16 tons/sq.in., specimen MNR 1/12 survived only 800,000 cycles at 0–15 tons/sq.in.; this specimen, however, failed from a weld defect close to the machined surface. Similarly, specimen MSR 1/4 had a low life at 0–17 tons/sq.in. because of an inclusion in the machined area.

It is known[3,4] that in the absence of defects, mild steel weld metal has a fatigue strength superior to that of mild steel plate with mill scale surfaces. If, therefore, machined butt welds in mild steel fail to reach the strength of the plain plate, the principal reason for this would be a weakness of the heat-affected zone. No evidence suggesting that such a weakness exists in mild steel butt welds has been produced in the present work.

Table XXIV

Comparison of test results for manual butt welds with and without stress relief

	Series	*Upper Limit Stress at 2×10^6 cycles, tons/sq.in.*	*Strength as percentage of series PN 2*
PN 2	½ in. plain plate with mill scale	16	100
MN 1	½ in. manual butt weld, not stress relieved	11·5	71·9
MS 1	½ in. manual butt weld, stress relieved	11·5	71·9
MNR 1	½ in. manual butt weld, not stress relieved but with reinforcement removed	16	100
MSR 1	½ in. manual butt weld, stress relieved and reinforcement removed	16	100

Effect of incorrect stress-relieving heat-treatment

As already stated, some of the test series which were treated commercially were incorrectly stress relieved. This applied to series PX, MX 1, MX 3 and MX 5, and was discovered after fatigue tests on these groups had been completed, when macro-sections cut from the welded joints for examination under the microscope revealed considerable grain growth at the plate surfaces, accompanied by carbon migration to the grain boundaries. This decarburized layer was about

Table XXV

Effect of stress-relieving treatments on mechanical properties of ½ in. BS.15 plate

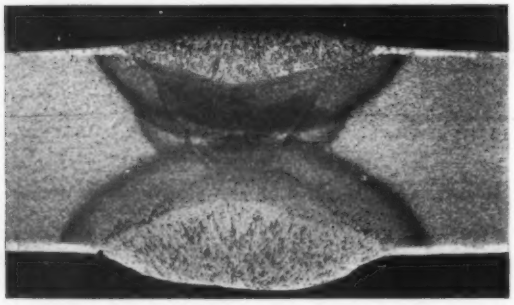
Property	*(1) As Received*	*(2) Stress Relieved*	*(3) Incorrectly Stress Relieved*	*Cols. $\frac{(2)-(1)}{(1)}$ 100%*	*Cols. $\frac{(3)-(1)}{(1)}$ 100%*
Yield point, tons/sq.in.	17·57	17·49	15·1	0	−14%
U.T.S., tons/sq.in.	29·2	28·35	25·2	−3%	−13½%
Elongation on $4\sqrt{A}$, %	36	43·3	42	+21%	+16%
Reduction in area, %	50·5	65·7	55·5	+30%	+10%

Table XXVI

Summary of test results for improperly stress relieved specimens

Series		*Upper Limit Stress at 2×10^6 cycles tons/sq.in.*	*Strength as percentage of series* PN 2	MN 1
PN 2	½ in. plain plate with mill scale, not stress relieved	16	100	—
PX	½ in. plain plate with mill scale, improperly stress relieved	14	87·5	—
MN 1	½ in. butt joint, not stress relieved	11·5	—	100
MX 1	½ in. butt joint (No. 1 preparation) improperly stress relieved	9·5	59·4	82·5
MX 3	½ in. D.P. butt joint (No. 3 preparation) improperly stress relieved	7	43·7	60·9
MX 5	1¼ in. butt joint (No. 5 preparation) improperly stress relieved	9·5	59·4	82·5

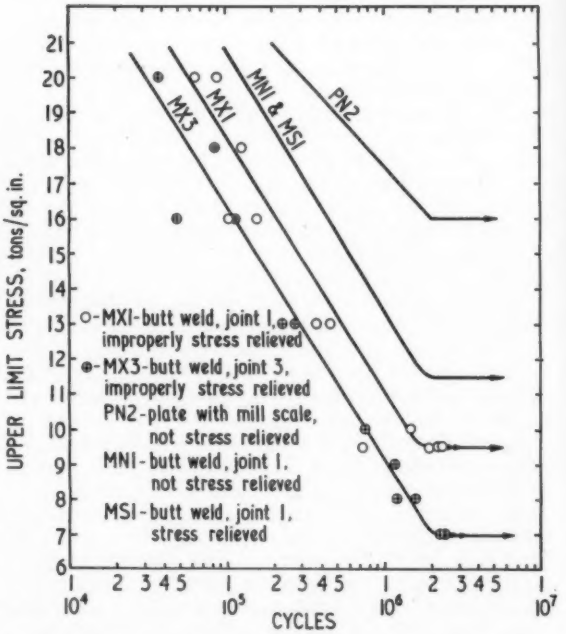
$\frac{1}{16}$ in. thick, and the core material contained spheroidized pearlite. It was determined that the probable incorrect heat-treatment to cause these effects had consisted of soaking at 650°C. for periods far longer than the usual one hour per inch of thickness. Figure 20 shows a macro-section of a typical specimen in the improperly stress-relieved condition.



20—*Decarburization of surfaces due to incorrect stress-relieving treatment*

To examine the influence of the modified metallurgical structure on the properties of the plate material, static tests were carried out on the incorrectly treated material, the specimens retaining the original mill scale and having a cross-section of $1\frac{1}{2}\times\frac{1}{2}$ in. Results of these tests are shown in Table III. Compared with material in the 'as-received' condition the effect of correct and incorrect heat-treatment on the mechanical properties of the material is therefore as shown in Table XXV.

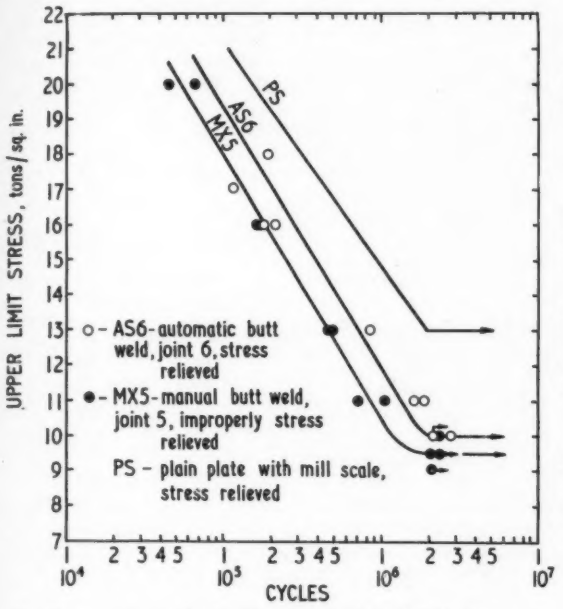
In Table XXVI the results of the fatigue tests have been summarized, and the fatigue strengths are compared with that of plain plate in the 'as-received' condition and that of series MN 1, manual butt welds not stress-relieved. The full results are set out in Tables XXVII–XXIX. The S/N diagrams for series MX 1 and MX 3 being shown in Fig. 21 and that for series MX 5 in Fig. 22.



21—*Fatigue test results for ½ in. butt welds incorrectly stress-relieved*

Comparing series PN 2 and PX, incorrect stress relief reduces the fatigue strength of plain plate by 12·5%. This compares with the 14% reduction in static tensile strength. The reduction in fatigue strength of nearly 40% for MX 3 joints is outstanding. This series, however, contained the manual deep-penetration welds which, apart from decarburization were characterized by unfavourable reinforcement shape and internal pores.

In the tests on series MX 1 and MX 5 all failures were initiated at the edge of the reinforcement. Most of the MX 3 group also failed in this way, but two cases of cracking in the weld metal were observed. Firstly, specimen MX 3/3 developed a major fatigue crack through the weld, starting from a cluster of internal pores near a corner of the section, and specimen MX 3/8 contained a small crack on the surface of the weld after failing from the edge of the reinforcement. This small crack was opened up, as shown in Fig. 23, to reveal a cluster of elongated pores near the surface. Specimen MX 3/3 was also examined closely after failure, and secondary cracks at the edge of the reinforcement were found. Thus, although two instances of weld-metal cracking from internal defects were noted, these were not associated with any further reduction of life, since the predominantly weak zone was the edge of the reinforcement, a discontinuity of unfavourable shape located in decarburized material.


UPPER LIMIT STRESS, tons/sq. in.
CYCLES
PS
AS6
MX5
○ - AS6-automatic butt weld, joint 6, stress relieved
● - MX5-manual butt weld, joint 5, improperly stress relieved
PS - plain plate with mill scale, stress relieved

22—Fatigue test results for 1¼ in. butt welds in BS.15 plate

Table XXVII

Summary of results for series MX 1
(½ in. manual butt weld, improperly stress relieved)

Specimen	*Upper Limit Stress tons/sq.in.*	*Million Cycles to Failure*	*Remarks*
MX 1/1	20	0·064	Four cracks at edges of weld reinforcement
MX 1/2	20	0·088	
MX 1/3	18	0·125	Four cracks at edges of weld reinforcement
MX 1/4	16	0·103	
MX 1/5	16	0·153	
MX 1/6	13	0·377	
MX 1/7	13	0·450	Crack at edge of weld reinforcement
MX 1/8	10	1·487	Two cracks at edges of weld reinforcement
MX 1/9	9·5	0·734	Crack at edge of weld reinforcement
MX 1/10	9·5	1·966	
MX 1/11	9·5	2·206	Unbroken. No fatigue cracks found under static load
MX 1/12	9·5	2·261	

Table XXVIII

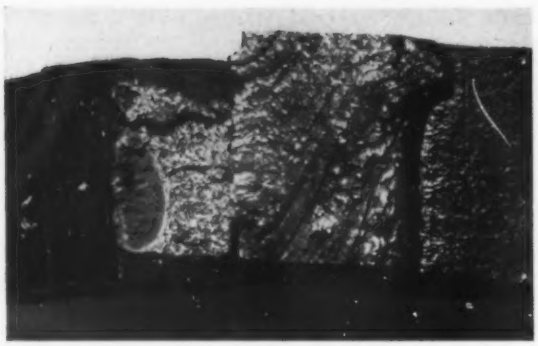
Summary of results for series MX 3
(½ in. manual butt weld (joint 3), improperly stress relieved)

Specimen	*Upper Limit Stress, tons/sq.in.*	*Million Cycles to Failure*	*Remarks*
MX 3/1	20	0·038	Failed from edge of weld reinforcement
MX 3/2	18	0·084	
MX 3/3	16	0·049	Failed through weld and from edge of reinforcement
MX 3/4	16	0·113	Failed from edge of weld reinforcement
MX 3/5	13	0·228	
MX 3/6	13	0·274	
MX 3/7	10	0·737	
MX 3/8	9	1·154	Failed from edge of reinforcement. Slight fissure in centre of one weld run
MX 3/9	8	1·200	Failed from edge of weld reinforcement
MX 3/10	8	1·587	
MX 3/11	7	2·222	Unbroken. No fatigue cracks found under static load
MX 3/12	7	2·461	

Table XXIX

Summary of results for series MX 5
(1¼ in. manual butt weld (joint 5), improperly stress relieved)

Specimen	*Upper Limit Stress, tons/sq.in.*	*Million Cycles to Failure*	*Remarks*
MX 5/1	20	0·045	Two cracks at edges of weld reinforcement
MX 5/2	20	0·066	Four cracks at edges of weld reinforcement
MX 5/3	16	0·164	Three cracks at edges of weld reinforcement
MX 5/4	16	0·171	
MX 5/5	13	0·469	
MX 5/6	13	0·483	
MX 5/7	11	0·711	Crack at edge of weld reinforcement
MX 5/8	11	1·024	Two cracks at edges of weld reinforcement
MX 5/9	10	2·367	Cracks found in static test at edge of reinforcement
MX 5/10	9·5	2·001	Unbroken. Static fracture away from weld
MX 5/11	9·5	2·346	
MX 5/12	9	2·081	



23—*Fatigue fracture initiated from cluster of pores in specimen MX 3/8 (manual deep-penetration weld)*

Figure 5 shows the shape of the reinforcement in section and Fig. 6 a typical condition for the internal porosity. Assuming the pores to be spherical, which underestimates their size, the highest reduction in area on a given plane normal to the direction of stressing was found to be about 1%. Whilst it can be stated that this degree of severity did not of itself result in a reduction in fatigue strength, the defects occurred in joints which would have had low fatigue strength in the absence of porosity. Thus it cannot be assumed that 1% porosity would have no influence on the strength of otherwise good quality welds. In this context quality refers to the absence of decarburization, but more particularly to good shape of reinforcement. The influence of decarburization alone is more accurately represented by comparing the results of the tests on the two groups of manual butt welds made with normal penetration electrodes; series MN 1, not stress relieved, and series MX 1, incorrectly stress relieved. In this case a difference of 17·5% in strength was obtained, and the MX 1 specimens gave a strength value at 2×10^6 cycles of 9½ tons/sq.in. only slightly below the observed strength range for normal transverse butt welds (series MN 1 being at the upper limit of the range).

Series MX 5, 1¼ in. butt welds incorrectly stress relieved, also gave a strength value of 9½ tons/sq.in. at 2×10^6 cycles, and is shown in Table XXVI to have the same percentage strength as series MX 1, since the same plain plate control value is referred to. However, the real plain plate strength for 1¼ in. plate (series PS) is 13 and not 16 tons/sq.in., so that the actual percentage strength for the MX 5 series should be taken as 73% rather than 59·4% (see p. 589). There is thus a larger reduction of strength in ½ in. welds because of decarburization than there is in the 1¼ in. welds, for the two base materials had been reduced to a similar condition at the surface by decarburization so that each tended to give the same strength value. The actual identity of strengths (9½ tons/sq.in.) in the last resort depended upon similarity of reinforcement shape and this, in fact, existed.

Effect of reinforcement shape

Several series of specimens were tested to obtain a qualitative result on the effect of reinforcement shape on the fatigue strength of butt welds. There were four basic types of specimen:

(*a*) Manual welds with the weld reinforcement left on
(*b*) Manual welds with the weld reinforcement removed
(*c*) Automatic welds with the weld reinforcement left on
(*d*) Automatic welds with the weld reinforcement removed.

The results of the fatigue tests on types (*a*) and (*b*), namely groups MN 1, MS 1, MNR 1, and MSR 1, are shown in Tables XX–XXIII and in Fig. 19, and have

Table XXX

Summary of fatigue test results for butt welds in ½ in. BS.15 plate

	Series	*Upper Limit Stress at 2×10^6 cycles tons/sq.in.*	*Strength as Percentage of Series PN 2*
PN 2	Plain plate with mill scale	16	100
MN 1	Manual weld, reinforcement on, not stress relieved	11½	71·9
MS 1	Manual weld, reinforcement on, stress relieved	11½	71·9
MNR 1	Manual weld reinforcement removed, not stress relieved	16	100
MSR 1	Manual weld, reinforcement removed, stress relieved	16	100
AS 2	Automatic weld (joint 2) reinforcement on, stress relieved	6½	40·5
AS 4	Ditto (joint 4)	7	43·8
AS 7	Ditto (joint 7)	11	68·8
ASR 2	Automatic weld (joint 2) reinforcement removed, stress relieved	16	100
ASR 4	Ditto (joint 4)	16	100

Table XXXI

Summary of results for series AS 2
(½ in. automatic butt weld (joint 2) stress relieved)

Specimen	*Upper Limit Stress, tons/sq.in.*	*Million Cycles to Failure*	*Remarks*
AS 2/1	20	0·029	Two cracks from edge of reinforcement
AS 2/2	18	0·039	
AS 2/3	16	0·103	
AS 2/4	13	0·145	Failure from edge of reinforcement
AS 2/5	10	0·412	Failure from corner of section at edge of reinforcement
AS 2/6	8	1·864	Failure from edge of reinforcement
AS 2/7	7	1·305	Two cracks at edge of weld reinforcement
AS 2/8	8	2·142	Unbroken. No cracks found in static test
AS 2/9	6·5	1·577	Failure from corner of section at edge of weld reinforcement
AS 2/10	6·5	2·013	Unbroken. No fatigue cracks observed after static test
AS 2/11	6·5	2·149	

Table XXXII

Summary of results for series AS 4
(½ in. automatic butt weld (joint 4), stress relieved)

Specimen	*Upper Limit Stress tons/sq.in.*	*Million Cycles to Failure*	*Remarks*
AS 4/1	16	0·036	Failure from corner of section at edge of reinforcement
AS 4/2	13	0·184	Failure from edge of reinforcement
AS 4/3	12	0·260	Failure from corner of section at edge of reinforcement
AS 4/4	10	0·914	Failure from edge of reinforcement
AS 4/5	9	2·031	
AS 4/6	8·5	0·507	
AS 4/7	8·5	0·539	Failure from corner of section at edge of reinforcement
AS 4/8	8·5	2·117	Unbroken. No fatigue cracks found in static test
AS 4/9	7·5	1·954	Failure from edge of reinforcement
AS 4/10	7	2·114	Unbroken. No fatigue cracks found in static test
AS 4/11	7	2·146	

Table XXXIII

Summary of results for series ASR 2
(½ in. automatic butt weld (joint 2), stress relieved and reinforcement removed)

Specimen	*Upper Limit Stress, tons/sq.in.*	*Million Cycles to Failure*	*Remarks*
ASR 2/1	21	0·314	Failed from rolled surface in transition zone
ASR 2/2	19	0·402	Failed from radius between machined and as-rolled sections
ASR 2/3	18	0·311	Failed from surface pithole
ASR 2/4	18	0·684	Failed from machined surface
ASR 2/5	17	2·231	Failed from rolled surface in transition zone
ASR 2/6	17	2·64	Unbroken. No fatigue cracks found in static test
ASR 2/7	16	1·6	Failed from rolled surface
ASR 2/8	16	1·689	Failed from rolled surface
ASR 2/9	16	2·449	Unbroken. No fatigue cracks found in static test

Table XXXIV

Summary of results for series ASR 4
(½ in. automatic butt weld (joint 4) stress relieved and reinforcement removed)

Specimen	*Upper Limit Stress, tons/sq.in.*	*Million Cycles to Failure*	*Remarks*
ASR 4/1	21	0·229	Failure from corner in transition zone
ASR 4/2	20	0·249	Failure from weld defect close to surface
ASR 4/3	20	0·289	Failure from surface at join of machined and rolled surfaces
ASR 4/4	19	0·237	Failure from surface at edge of weld
ASR 4/5	18	0·801	Failure from rolled surface
ASR 4/6	18	0·889	Failure from machined surface
ASR 4/7	17	2·421	Unbroken. No fatigue cracks observed after static test
ASR 4/8	16	2·051	
ASR 4/9	16	2·325	

Table XXXV

Summary of results for series AS 7
(½ in. automatic butt weld (joint 7), stress relieved)

Specimen	*Upper Limit Stress, tons/sq.in.*	*Million Cycles to Failure*	*Remarks*
AS 7/1	18	0·118	Failure from edge of weld reinforcement
AS 7/2	16	0·203	
AS 7/3	14	0·329	
AS 7/4	12	0·436	
AS 7/5	12	0·863	
AS 7/6	11	2·156	Failure from pithole in parent plate
AS 7/7	11	2·483	Unbroken. No fatigue cracks observed in static test
AS 7/8	10	2·248	

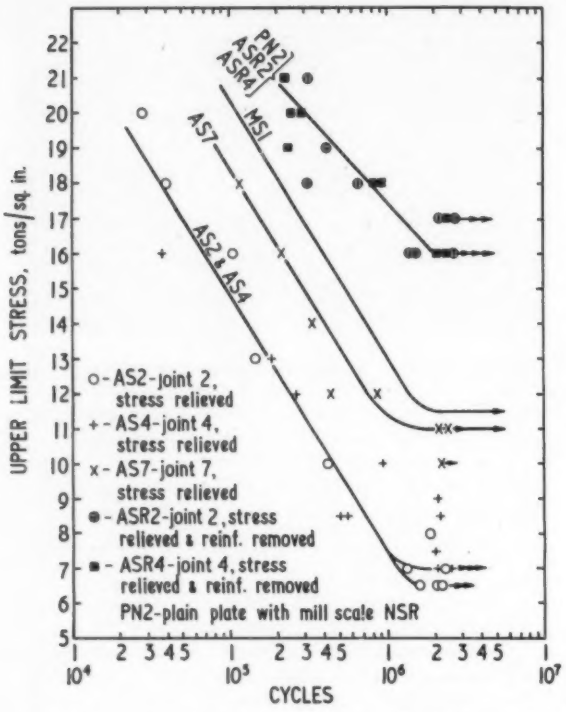
already been dealt with (see p. 582). However, the fatigue strength figures for these groups at 2×10^6 cycles are quoted again in Table XXX.

The automatic welds, types (*c*) and (*d*) were made by the submerged-arc process and were tested in the stress-relieved condition. Type (*c*), made up of series AS 2, AS 4, and AS 7, had the reinforcement left on; the results for these three series are given in Tables XXXI, XXXII and XXXV. Type (*d*) included series ASR 2 and ASR 4, these being similar to AS 2 and AS 4 but with the reinforcement removed; the relevant test results are given in Tables XXXII and XXXIV.

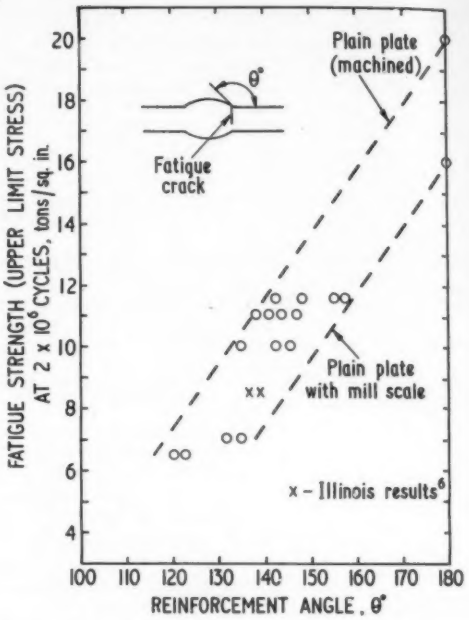
The S/N curves for the five series are shown in Fig. 24, and Table XXX summarizes the fatigue strengths obtained.

Except for specimen AS 7/6, all failures in the three series of automatic welds with the reinforcement left on were initiated at the edge of the reinforcement. In series AS 2 and AS 4 it was notable that failure was usually initiated over a considerable width of cross-section, as indicated in Fig. 25.

From a comparison of the results quoted in Table XXX it is apparent that among joints with the reinforcement left on the two automatically welded joints AS 2 and AS 4 are significantly lower in strength than the remainder. They have, in fact, fatigue strengths equivalent to about 60% of the strength of the manually welded joints and of the automatically welded joints, series AS 7. However, a comparison of the results for welds made both manually and automatically, but each having the reinforcement machined off, shows that there is no real difference, each having the same strength as plain plate. It is therefore possible to conclude that the


UPPER LIMIT STRESS, tons/sq. in.
CYCLES
PN2
ASR2
ASR4
MS1
AS7
AS2 & AS4
○ - AS2-joint 2, stress relieved
+ - AS4-joint 4, stress relieved
x - AS7-joint 7, stress relieved
● - ASR2-joint 2, stress relieved & reinf. removed
■ - ASR4-joint 4, stress relieved & reinf. removed
PN2-plain plate with mill scale NSR

24—*Fatigue test results for ½ in. automatic butt welds*


FATIGUE STRENGTH (UPPER LIMIT STRESS) AT 2 x 10⁶ CYCLES, tons/sq. in.
REINFORCEMENT ANGLE, θ°
θ°
Fatigue crack
Plain plate (machined)
Plain plate with mill scale
x - Illinois results⁶

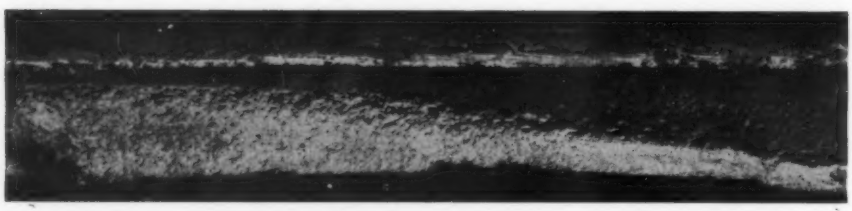
26—*Fatigue strength plotted against reinforcement angle*

reduced fatigue strength of series AS 2 and AS 4 specimens is not due to any metallurgical factors, for if this were so a difference in strength would be expected between groups MNR 1 and MSR 1 and ASR 2 and ASR 4. Also, since groups AS 2, AS 4 and MS 1 were stress relieved and group MN 1 had the same fatigue strength as group MS 1, the difference is not due to residual stresses. Hence, it seems reasonable to assume that the predominant factor in determining the strength of welds of this type is the notch effect at the edge of the weld reinforcement—the point from which most of the fractures started—and this notch effect depends on the shape of the reinforcement. Thus, specimens without reinforcement suffered no notch effect, so that they gave the same fatigue strength as plain plate.

The macrosections of each of the various joint types used in this investigation are shown in Fig. 5, and illustrate the reinforcement shapes involved. For simplicity it can be assumed that reinforcement shape is governed by three variables:

(*a*) Height of reinforcement above the plate surface
(*b*) Width of reinforcement
(*c*) Angle between the reinforcement and plate surfaces at their point of intersection.

As already mentioned, failure of the automatically welded specimens was characterized by a considerable length of crack initiation, whereas manually welded specimens failed from a few isolated points. However, for both types of weld, there was no great variation in height or width of reinforcement along the length of the welds. This suggested that the major factor to be considered was reinforcement angle; *i.e.* the angle θ (see Fig. 26) subtended by the plate surface and a tangent to the weld reinforcement bead at its junction with the plate. This angle was found to be variable along the length of a weld, particularly in manually welded joints, and it appeared that failure normally originated at the point of minimum angle. Macrosections were therefore cut from several specimens at the actual point of crack initiation and the relevant angle was measured using a projection microscope. The measured angle was then plotted against the fatigue strength at 2×10^6 cycles of the particular test



25—*Failure of AS 2 specimen (automatic weld) showing fatigue initiation over full width*

series from which the specimen originated; the resulting curve is shown in Fig. 26. Since fatigue strength values are essentially determined by unbroken specimens, the fractured specimens taken for sectioning were selected from those which had given mean results lying on or close to the relevant fatigue curve.

The recorded scatter in the manually welded series was approximately 15°, whilst that in the automatically welded series was somewhat less, but all the experimental points can be enclosed in a scatter band using as its two upper limits (at $\theta=180°$) the strength of plain plate with and without mill scale. In the absence of further experimental results a straight scatter band has been plotted, and it is considered that this rough relationship between θ and fatigue strength does indicate that the terms 'good' and 'bad' reinforcement shape might be capable of better definition.

Butt welds in 1¼ in. thick plate

Tests were carried out on two types of butt joint in 1¼ in. plate. Series MX 5, specimens with manual welds, was incorrectly stress relieved, and series AS 6 was automatically welded (submerged-arc) and properly stress relieved. The results are set out in Tables XXIX and XXXVI and are shown graphically in Fig. 22.

Throughout these tests the failures were of the type expected for good quality welds, the fractures being initiated at one or more edges of the weld reinforcement (Fig. 27). But in series MX 5, which had a decarburized surface layer, there was a strong tendency for several cracks to start at the edge of the weld reinforcement on each specimen.

The established upper limit stress at 2×10^6 cycles for series MX 5 was 9½ tons/sq.in. and for series AS 6 it was 10 tons/sq.in. These results are summarized in Table XXXVII, in which the result for series PS, 1¼ in. BS.15 plain plate, is used for establishing percentage strength values. The two values of 73% and 77% for series MX 5 and AS 6 respectively appear, at first sight, to be particularly good for joints with the reinforcement left on, but it will be seen that the plain plate strength used as a control basis is low, *i.e.*, 13 tons/sq.in. as compared with 16 tons/sq.in. for ½ in. plate.

This difference is primarily due to the influence of surface conditions (see p. 577). In terms of absolute fatigue strengths the two 1¼ in. joints are directly comparable with joints in ½ in. thick material. Thus series MX 5, manually welded and incorrectly stress relieved, has the same strength as series MX 1, also manually welded and incorrectly stress relieved. The automatically welded joints, series AS 6, with a strength of 10 tons/sq.in. can be compared with series AS 7, automatic welds in ½ in. plate, having a strength of 11 tons/sq.in. The small difference here is accountable on the basis of a slight general difference in reinforcement shape.

Table XXXVI

Summary of results for series AS 6
(1¼ in. automatic butt weld (joint 6) stress relieved)

Specimen	*Upper Limit Stress, tons/sq.in.*	*Million Cycles to Failure*	*Remarks*
AS 6/1	18	0·196	Failed from edge of reinforcement
AS 6/2	17	0·117	
AS 6/3	16	0·177	
AS 6/4	16	0·214	
AS 6/5	13	0·837	
AS 6/6	11	1·619	
AS 6/7	11	1·893	
AS 6/8	10	2·119	Unbroken. Fractured statically after fatigue test but no fatigue cracks observed
AS 6/9	10	2·742	

Table XXXVII

Summary of test results for butt welds
(In 1¼ in. thick BS.15 plate)

	Series	*Upper Limit Stress at 2×10^6 cycles, tons/sq.in.*	*Strength as Percentage of Series PS*
PS	1¼ in. plain plate with mill scale, stress relieved	13	100
MX 5	1¼ in. manual butt joint, improperly stress relieved	9·5	73
AS 6	1¼ in. automatic butt joint, stress relieved	10	77

27—*Failure of MX 5 specimen (manual weld in 1¼ in. BS.15 plate)*

Comparison of Present Work with other Published Results

It is not intended here to make an extensive review of the literature, but to draw broad comparisons with a few other investigations in which general aims and means have been similar. It will have been noted from the present work that in the absence of any other variables, a significant dispersion of fatigue strength values for transverse butt welds in mild steel may occur as the result of differences in reinforcement shape. This factor is seldom specified in published research reports, and it follows that any accuracy in making comparisons must be limited. There can be no question of confirming or denying results between two different investigations; indeed, even with absolutely identical specimens, identity of result would then depend upon the degree to which testing techniques were comparable. Nevertheless, selected comparisons can help to consolidate general findings, and it is in this sense that the following review is made.

Possibly the most comprehensive programme of work on the fatigue behaviour of welded joints is represented by the series of investigations carried out, and still continuing, at the University of Illinois, U.S.A. These investigations have, among other things, dealt extensively with transverse butt welds, mainly in steel corresponding to the ASTM–A 7 specification (26·8–32·2 tons/sq.in. U.T.S.; 14·7 tons/sq.in. minimum yield stress). For much of the comparative work a pulsating tension cycle (lower limit zero) has been used, the testing frequency being of the order of 180 reversals per min. The general conditions are thus markedly similar to the present work. However, a different method of arriving at definitive fatigue strength values has been used by Illinois University. In general, the tests on a given group of specimens have been planned to give two strength values, one corresponding to failure in 100,000 cycles (F_1) and the other corresponding to failure in 2,000,000 cycles (F_{20}).

The values of F_1 and F_{20} are computed from the results of tests by means of the empirical equation:

$$F_n = S(N/n)^k, \text{ where}$$

S = maximum stress in the stress cycle
N = number of cycles to failure for the test in question
F_n = the fatigue strength corresponding to failure at a number of cycles n.*
k = experimental constant depending upon geometrical characteristics of the specimen and the mechanical properties of the metal; determined for each group of results from the slope of the S/N curve.[5]

To reduce the error in F_n, resulting from the use of an inaccurate value of k, an arbitrary rule is used to divide the experimental results, so that F_1 is determined from tests for which n is less than 600,000 and F_{20} is determined from tests for which n is greater than 300,000. Results between 300,000 and 600,000 are used in determining both F_1 and F_{20}.

It is convenient to discuss the results of this work, in relation to the present investigation, under general subject headings. The results considered are taken from four separate reports.[6–9]

* To simplify typesetting F_n has here been reduced by a factor of 100,000 (*e.g.* $F_{20} = F_{2,000,000}$).

Table XXXVIII

Comparison of plain plate results (mill scale on): University of Illinois and BWRA

Ref.	*Plate Thickness, in.*	*Source*	*U.T.S., tons/sq.in.*	*Fatigue Strength, tons/sq.in.*
1	½	BWRA (Series PN 2)	28·1–29·0	16
2	½	University of Illinois	26·1	15·5
3	⅝		26·3–28·3	14·1
4	1¼	BWRA (Series PS)	27·5	13

Table XXXIX

Summary of results

(BWRA and University of Illinois.) For butt welds with reinforcement removed

Ref.	*Thickness, in.*	*Type of Electrode or Welding Process*	*Stress Relieved*	*Source*	*Fatigue Strength tons/sq.in.*
1	½	E.319	No (MNR 1)	BWRA	16
2	½	E.319	Yes (MSR 1)		16
3	½	Automatic	Yes (ASR 2)		16
4	½	Automatic	Yes (ASR 4)		16
5	½	E.6010	No	University of Illinois (Bull. No. 384)	12·9
6	½	E.6010	Yes		13
7	½	E.6012	No		11·8
8	½	E.6012	Yes		13·5
9	⅞	Manual (reinforcement machined off)	No	University of Illinois (Bull. No. 327)	12·7
10	⅞	Manual (reinforcement machined off)	Yes		12·4
11	⅞	Manual (reinforcement ground off)	No		11·8

Plain plate properties

A comparison of the results obtained with plain plate specimens shows a marked similarity between the materials used in the Illinois University and BWRA investigations. This comparison is made in Table XXXVIII and applies to specimens with mill scale left on; the fatigue strength values quoted are for 2×10^6 cycles.

Transverse butt welds with reinforcement removed

In Table XXXIX the results of four groups of tests on welded specimens in $\frac{1}{2}$ in. thick mild steel (A7) are summarized from one of the Illinois University reports. After welding, these specimens had the reinforcement machined flush with the plate and the mill scale ground off; they were finished by draw filing in the direction of loading. Further results are given in this table for $\frac{7}{8}$ in. thick butt welded specimens, tested at Illinois University, in which the reinforcement and mill scale was ground or machined off. It is improbable that any one of these conditions was directly equivalent to that given by the machining and hand polishing treatment applied to the BWRA specimens, but a general comparison of all results is made in the table.

The American results fall within a range of approximately 77–90% of the corresponding plain plate strengths (Table XXXVIII) and are, therefore, somewhat below the BWRA values. It has been mentioned that the finished surfaces may not have been exactly similar, but from an analysis of modes of failure it is evident that weld quality (*i.e.* the presence or absence of defects) was probably a more variable factor. For example, in the four groups 5–8 a total of 25 fractures was obtained, of which 20 (or 80%) were located in the weld metal. In the BWRA tests on manual welds (1 and 2 in the table) only 5 out of 18 fractures (28%) were located in weld metal. The deduction here is essentially qualitative, but is perhaps further reinforced by the fact that in the lowest strength group of the Illinois results, 11·8 tons/sq.in. for specimens 7, all of the fractures had been initiated in the weld metal. In the tests on the $\frac{7}{8}$ in. thick specimens the mode of failure was more variable, as in the BWRA tests. The two groups in which the reinforcement had been machined off reached 88–90% of the plain plate strength, but there was a drop to 83% for ground specimens. It is implied that this was due primarily to internal defects.

Manual transverse butt welds with reinforcement left on

Excluding those series that had been incorrectly stress relieved, the basic fatigue strength values derived from the BWRA investigation for manual welds with the reinforcement left on are represented by the limits of 10–11$\frac{1}{2}$ tons/sq.in. This range applies only to $\frac{1}{2}$ in. welds. From the Illinois University programme, eleven groups of tests can be singled out for comparison. These involved the testing of similar types of specimen, but in thicknesses ranging from $\frac{1}{2}$ in. to $\frac{7}{8}$ in. The average fatigue strengths obtained were between the limits of 9$\frac{1}{2}$–11$\frac{3}{4}$ tons/sq.in.

The excellent degree of correspondence between these strength values is a little surprising, since six of the Illinois test groups were manufactured commercially with no control imposed other than that normally employed by the fabricator in applying the AWS Specifications for Welded Highway and Railway Bridges (1939). The six groups, all $\frac{7}{8}$ in. thickness plate were welded in the downhand position by qualified welders, and the fabricators were given freedom of choice in the matter of welding procedure. In general these groups were associated with strength values at the lower end of the range (*i.e.*, 9$\frac{1}{2}$ tons/sq.in.) and a significant number of specimens failed from internal defects; nonetheless the actual strength values are good and it is evident that the defects did not cause any marked reduction of strength, even if they frequently initiated failure.

In an extension of the work on commercial quality welds, tests were carried out at Illinois on $\frac{7}{8}$ in. thick transverse butt welds made in various positions, including two groups welded under site conditions. The average strength values recorded in these tests were:

(*a*) *Plates welded in downhand position from one side and overhead position from other side*

Specimens from	1st supplier	–7$\frac{1}{2}$	tons/sq.in.
,,	,,	2nd supplier	–9	,,	,,
,,	,,	3rd supplier	–8$\frac{1}{2}$	,,	,,
,,	,,	4th supplier	–8$\frac{1}{2}$	,,	,,

In these series, which collectively present incremental reductions of strength, some weld metal failures occurred, but failure from the edge of the reinforcement appeared to be the predominant mode. Reference is made to the presence of undercutting, porosity, and slag inclusions; these defects were usually associated with the overhead portion of the weld. It is not specifically stated that the fatigue failures were also associated with this side of the joint, but the occurrence of undercutting there suggests that this would be so, and it is probable that the overhead reinforcement shape would in any case have been the less favourable of the two.

(*b*) *Plates welded in the vertical position*

Specimens from	1st supplier	–8$\frac{1}{2}$	tons/sq.in.
,,	,,	2nd supplier	–8	,,	,,
,,	,,	3rd supplier	–9$\frac{1}{2}$	,,	,,

The same defects as noted above were found in these specimens and, in addition, the group giving a strength of 8 tons/sq.in. contained unfused areas and more extensive slag inclusions in the root area. Once again, however, failure at the edge of reinforcement predominated.

(*c*) *Site welds made in vertical plates with joints in the vertical and horizontal positions*

Vertical welds	1st supplier	–8$\frac{1}{4}$	tons/sq.in.
	2nd supplier	–7	,,	,,
Horizontal welds	1st supplier	–8$\frac{1}{4}$	,,	,,
	2nd supplier	–7$\frac{3}{4}$	,,	,,

The vertical and horizontal welds from the first supplier had average strength values equivalent to the shop welded series of the commercially made joints. As before, these welds failed primarily from the edge

of the reinforcement. The reduced strength values of the welds from the second supplier could, however, be clearly associated with the influence of internal defects, notably lack of penetration. These specimens did not comply with the particular specification that was adopted for the production of the site welded joints.

It has not been part of the present BWRA programme to study the influence of weld quality in the same extensive way as has been done in the Illinois University work already described. However, the results stated above are of direct interest since they give added emphasis to the importance of external contour in determining the fatigue strength of transverse butt welds. The extent to which this factor operates in commercially made manual welds containing some defects is evident from the Illinois work and this general observation usefully augments the BWRA investigation.

Automatically welded transverse butt joints

Fatigue tests on one group of $\frac{7}{8}$ in. thick specimens containing transverse butt welds made by automatic (submerged-arc) welding were carried out at Illinois. These gave a fatigue strength of $8\frac{1}{2}$ tons/sq.in. More recent tests on joints of this kind have been reported by Martin and Falco.[10] These later tests were made on transverse welds in $\frac{1}{2}$ in. mild steel plate (28 tons/sq.in. U.T.S.; 17 tons/sq.in. yield stress) deposited both by the submerged- and the visible-arc (covered electrode) processes. The load cycle was nominally pulsating tension, a small positive preload being used. Taking fatigue strength as the range of stress obtained at 2×10^6 cycles, both series of specimens gave the same strength result of $8\frac{1}{2}$ tons/sq.in.

This common strength value is intermediate between the values obtained in the BWRA programme where, for specimens with the reinforcement left on, the following figures were derived for submerged-arc welds:

Series AS 2 ($\frac{1}{2}$ in. joint 2)–$6\frac{1}{2}$ tons/sq.in.
„ AS 4 ($\frac{1}{2}$ in. joint 4)–7 „ „
„ AS 7 ($\frac{1}{2}$ in. joint 7)–11 „ „
„ AS 6 ($1\frac{1}{4}$ in. joint 6)–10 „ „

The differences in strength are ascribed to the influence of reinforcement shape, which might be further defined by the strength/θ diagram, Fig. 26. Illustrated macrosections of two of the joints from the Illinois tests allow a rough measure of θ to be made, for the edge of the reinforcement that initiated failure. The measured values are 137° and 139° respectively, and Fig. 26 shows that these fall within the band of measurements made on BWRA specimens. Similar measurements can be made for the second investigation,[10] but the two macrosections illustrated in the report do not indicate at which point failure was initiated. The minimum angles on these two sections are 120°, which is outside the scatter band of Fig. 26, and 131°, which is inside the band.

It is not, perhaps, fully justified to take isolated angle measurements as indicative of the shape of the reinforcement for a test group as a whole. The amount of scatter for a test group is probably reduced by taking only 'critical' measurements; *i.e.* the values of θ at the point of crack initiation for specimens which lie on the mean curve. Even so, this procedure by no means eliminates variations of θ, for either manual or automatic welds.

Conclusions

The following conclusions may be drawn from these tests, the fatigue strengths being based on a life of 2×10^6 cycles:

(1) For axial loading under a pulsating tension cycle (lower limit zero) the fatigue strength of $\frac{1}{2}$ in. thick mild steel to BS.15 is 19 tons/sq.in. when the surfaces are machined and dressed by hand draw filing. Tested in the 'as-rolled' conditions, with mill scale on, similar plate has a fatigue strength of 16 tons/sq.in., so that the effect of mill scale is to reduce fatigue strength by 15%. The result obtained for BS.15 plate with mill scale on is in good agreement with other reported results obtained from fatigue tests on similar thicknesses and types of mild steel.

(2) For the same kind of test, $1\frac{1}{4}$ in. thick BS.15 mild steel has a fatigue strength of 13 tons/sq.in. with mill scale on. The reduction of 19% below the strength of $\frac{1}{2}$ in. plate is attributed primarily to increased surface roughness.

(3) The fatigue strengths of two grades of 1 in. thick steel to BS.2762 (ND I and ND IV grades) were both found to be 16 tons/sq.in. when tested with the mill scale on. From a number of tests on the ND IV grade it was indicated that this strength value is dependent upon a reasonably good rolled surface. It was also indicated in the tests on both grades that inclusions in the plate do not adversely influence fatigue behaviour under axial tension loading.

(4) Transverse butt welds in $\frac{1}{2}$ in. thick BS.15 steel, made either manually with rutile electrodes, or automatically by the submerged-arc process, have fatigue strengths equal to that of BS.15 plain plate with the mill scale on when

(*a*) the reinforcement is removed by machining, followed by hand polishing;
(*b*) there are no included defects in the weld.

(5) The application of a 650°C. stress-relieving treatment to transverse butt weld specimens in $\frac{1}{2}$ in. BS.15 plate, 4 in. wide, does not influence fatigue strength, irrespective of whether the reinforcement is left on or machined off.

(6) Incorrect stress relieving procedures may cause a reduction of fatigue strength if decarburization of the surface is produced. In the present tests some specimens suffered prolonged heating at 650°C. and were decarburized for a depth of approximately $\frac{1}{16}$ in. In this condition the fatigue strengths of plain plate and butt welded specimens were reduced by 12·5% and 17·5% respectively.

(7) The fatigue strength of otherwise good quality manual and automatic transverse butt welds depends upon the shape of the reinforcement and in particular on the severity of the configuration at the edge of the reinforcement. The angle subtended by the plate surface and the tangent to the reinforcement at its junction with the plate appears qualitatively to give a measure of this severity.

(8) With the reinforcement left on, good quality manual welds (transverse butt) in $\frac{1}{2}$ in. thick BS.15

steel have fatigue strengths in the range 10–11½ tons/sq.in. The term 'good quality' as used here refers to freedom from significant weld defects and a good reinforcement shape as produced by a skilled welder working in the downhand position with rutile electrodes. This strength range, which is in close agreement with other reported results, covers specimens in which the joint preparation is made by machining and by hand or machine gas-cutting. A survey of other investigations shows that fatigue strengths below 10 tons/sq.in. may be found for the same kind of joint when the welding is done under shop or site conditions, and particularly when welding positions other than downhand are used. The shape of reinforcement obtained under these conditions probably plays a significant part in causing the reduction of strength, but the influence of defects also cannot be ignored.

(9) With the reinforcement left on, the fatigue strength of transverse butt welds in BS.15 plate made by the automatic submerged-arc process may vary between 6½ and 11 tons/sq.in. In the present tests, welds made under typical shop conditions were associated with the lower strength values, and the one series giving a strength of 11 tons/sq.in. were specially prepared, using a procedure designed to produce a more favourable shape of reinforcement.

The lower values were equivalent to the fatigue strength found for manual welds in ½ in. BS.15 plate, made with deep-penetration electrodes. Although these deep-penetration welds had been incorrectly stress relieved, it was probable that their poor reinforcement shape was an equally important factor.

Acknowledgments

The authors wish to acknowledge their indebtedness to the Director of Research for his encouragement and expert help with all aspects of the work. The members of the D.2 (formerly FE.8) Committee are also thanked for their continued interest in the investigation. In particular, thanks are due to Mr. H. N. Pemberton and Mr. James Turnbull, formerly Chairman of the FE.8 and FE.21 Committees respectively, whose advice and guidance in the planning of this investigation were especially valuable. The encouragement given by Dr. H. G. Taylor, formerly Director of Research, is also gratefully acknowledged.

The following member firms gave direct assistance in many ways for which the authors are pleased to record their gratitude: Colvilles Ltd.; Murex Welding Processes Ltd.; Quasi-Arc Ltd.; Alexander Stephens and Son, Ltd.; Stewarts and Lloyds Ltd.; John Thompson (Wolverhampton) Ltd.; Whessoe Ltd.

Some of the testing was carried out in the Fatigue Laboratory at Cambridge University Engineering Laboratory, the facilities being provided by Professor J. F. Baker. Assistance with certain metallurgical aspects was given by Professor G. Wesley Austin and Mr. G. C. Smith of the Metallurgical Department, Cambridge University. The authors are keenly appreciative of this help.

The attempt to define reinforcement shapes more closely, by measuring angles at the edge of the reinforcement, arose out of discussions with Rolls Royce Ltd. who have applied the same idea in their own fatigue testing programmes.

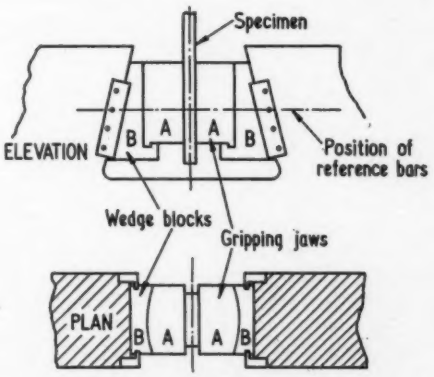
Finally, it is the authors' pleasure to acknowledge the assistance given by their colleagues, Mr. H. J. Tuck, who conducted the tests, Mr. P. H. R. Lane, Mr. E. Lawrence and Mr. R. Males.

APPENDIX

Specimen Centering Device for Losenhausen UHS 200 Fatigue Testing Machine

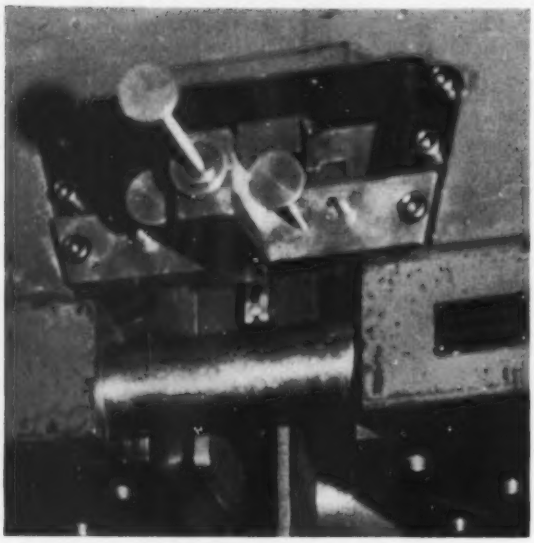
One of the grip assemblies for axial loading of plate specimens is shown in Fig. 28. The replaceable gripping jaws *A* are mounted on sliding wedge blocks *B*, the contacting surfaces being of circular form with respect to the vertical axis of the assembly. By sliding the grips horizontally in the wedge blocks the grip faces are thus given a rotation about the vertical axis and this permits the gripping of plates of asymmetrical section, or the gripping of uniform thickness plates containing a slight twist in length. The positioning of the various elements in the grip assembly, including the specimens, thus plays an important part in ensuring axiality of loading, particularly about the major axis of the specimen.

The specimen centering device was made to reduce setting-up times by enabling controlled adjustments of the position of all elements in the grip assembly to be made. It consists essentially of two pairs of reference bars bolted across the sides of the grip assembly; one is shown mounted on the machine in Fig. 29 and in further detail in Fig. 30. One pair is attached to the upper, and one to the lower, grip assembly of the machine. By means of adjustment screws the five elements, two wedge blocks, two gripping jaws, and the specimen, may be moved horizontally and fixed in a given position.

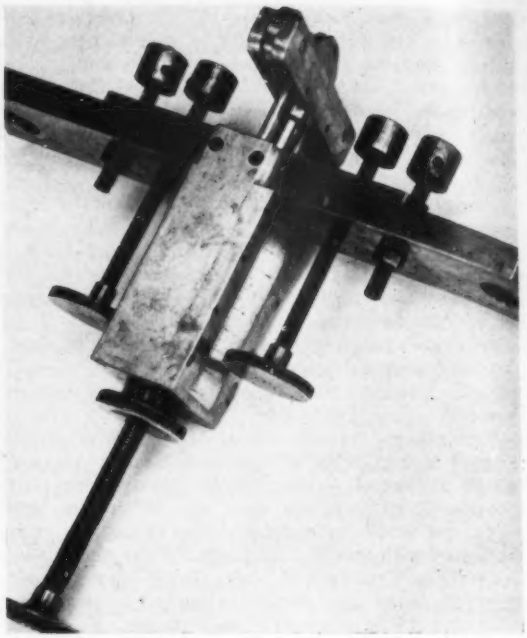


28—Testing machine grip assembly

The ends of the four outer adjusting screws, abutting the grip elements, contain captive balls to allow vertical sliding of the elements. On one side of the machine jaws the specimen is similarly held by a ball-ended screw, and on the opposing side the adjusting screw is attached to a vertical bar containing two ball bearings which abut on the edge of the



29—*Centering device mounted on the side of one of the grip assemblies*



30—*Details of centering device*

specimen. In this way the specimen is given a three-point support and is prevented from twisting during any vertical movement of the jaws. Scaled hand wheels are attached to the outer ends of the grip and specimen adjusting screws on one side of the assembly, and these permit precise transverse movements to be made.

The centering device is used in conjunction with extensometers or strain gauges to achieve minimum bending about the major axis of the specimen. Bending about the minor axis is dependent upon specimen straightness, but is probably less critical in its effects upon fatigue behaviour. For plain plate specimens, straightened before testing, it has been found that minor axis bending is usually of the order of 3–5%, but larger values are possible with welded specimens. In each case, however, the use of the centering device enables major axis bending to be maintained at not more than 2%.

A short series of experiments was carried out on welded specimens to observe the effect of minor axis bending, and it was found that even when the bending stress was permitted to reach 20% of the mean stress applied, no systematic correlation existed between the position of failure initiation in the cross-section and the stress conditions on that cross-section. Thus it was frequently observed that failure had started on the side where bending had reduced the range of stress applied. It should be emphasized here that the specimens contained welded joints with the reinforcement left on, so that there were superimposed stress concentration effects.

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B.W.R.A. REPORT

Raising of Studs on Metal Surfaces

By E. J. French, B.SC., A.M.I.E.E.

During experimental work a process was discovered by which molten metal can be expelled from a spot weld and cast to form a stud, welded to the parent metal. Generally the metal required to form the stud is obtained from the molten zone produced in the interface between the parts being welded, but protuberances of limited size have been raised from a single sheet of metal. Cylindrical studs have been formed in a range of ferrous and non-ferrous materials. More complex shapes may be produced, and studs may be cast around metallic or non-metallic inserts. Among possible applications of the new process is the forming of projections in thick material in preparation for projection welding.

Control of Splashing

In making a spot weld, if the applied electrode force is too low, or if the welding current is too high, the constraint upon the molten weld metal may be insufficient to prevent its violent expulsion between the members being welded. Sometimes, with high current densities, this phenomenon of splashing may occur at the surfaces in contact with the electrodes, or at the interface between the pieces of metal being welded, or at both surfaces. Splashing causes lower spot weld strengths by destroying the continuous peripheral zone from which most of the strength accrues. It causes voids and cavities in the weld and disfigures the welded product.

Patent applications have recently been filed* for a new process in which the splashing is controlled. Instead of the molten metal being expelled outwards from the weld it is directed into a cavity in the face of the electrode, where it freezes to form a protuberance of a predetermined shape, welded to the parent metal. Since the periphery of the weld is not disturbed, not only is the expelled metal employed to form the required shape, but by suitable control of the welding variables, the disadvantages normally associated with splashing are avoided.

* Provisional Patent Specification No. 8211/58. This has been taken out by the Atomic Energy Authority to which, under the contract, all rights for atomic energy and British Governments departments applications belong. The Atomic Energy Authority is granting a royalty-free licence to the National Research Development Corporation and the Corporation will exploit the invention for non-atomic energy applications on behalf of the British Welding Research Association. A survey is being made by the Association to determine the more important potential applications.

The Electrode

A cylindrical stud on flat sheet is the simplest shape which may be formed by this method. The electrode may be prepared, as shown in Fig. 1, by drilling a cylindrical hole at right angles to the centre of the welding face of an ordinary truncated cone type spot-welding electrode. Such an electrode may be used as for spot welding, but with a higher welding current; the distribution of pressure on the metal then encourages splashing into the cavity, where a casting of the desired shape is formed. The chilling action of the

Report A3/2/58 of the British Welding Research Association, issued to members in May 1959.
Mr. French is a Principal Research Officer with the Association.

1—*Electrode assembly for forming cylindrical stud*

water-cooled copper electrode is such that even metals with very high melting points may be cast in this way.

Using Two or More Sheets

When the prepared electrode is used simply as described to spot weld together two or more sheets of metal, then a stud is formed, depending on the welding conditions used. However, the process tends to be

2—*Section through stud raised from two sheets of titanium. The upper sheet was drilled to facilitate the movement of molten metal*

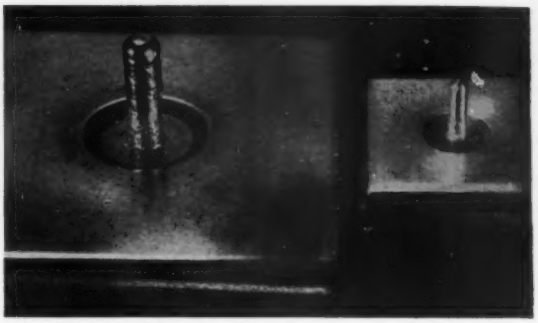
variable when used in this way; unsound castings may be produced and external splashing may occur. More consistent results may be achieved by drilling a hole in the sheet of metal adjacent to the cavity. This hole provides an easy path for the movement of molten metal from the weld nugget to the mould. Figure 2 shows a section through a stud formed from two sheets of titanium; the sheet on the stud side originally had a hole in it adjacent to the cavity in the electrode.

A washer may be used instead of the second sheet of metal under the prepared electrode, and if the volume of metal in the washer is approximately equal to that required for the casting, and if the dimensions of the washer match those of the electrode tip, then there is a minimum disturbance of the surface of the metal around the cast stud. A prepared electrode in contact with a steel washer was used on each side of a thin sheet of steel to produce the double-studded specimen shown in Fig. 3.

3—*Studs produced on thin steel sheet, washers being used to provide the necessary metal*

Materials

Cylindrical studs have been formed in a number of different metals, including deep-drawing quality steel, Fortiweld, Corten, steel to specification 3S3, (0·22 %C), 18/8 stainless steel, Nimonics 75, 80*A*, and 90, aluminium and magnesium. As in spot welding, higher currents are required for metals with high thermal and electrical conductivities, and the largest size of aluminium stud raised with the 100 kVA projection welder used in the experiments was smaller than the equivalent size of steel stud. The two are shown together in Fig. 4.



4—*The steel stud on the left is much larger than the biggest aluminium stud produced on the same welding machine*

Using only One Sheet

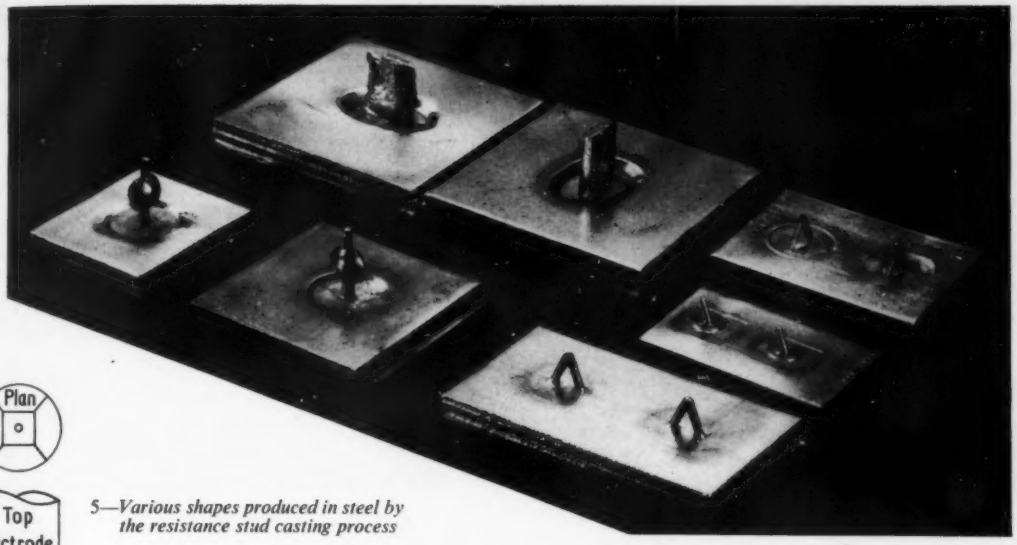
The size of protuberance which can be produced on a single sheet of metal is much less than that with two or more sheets, since it is more difficult to produce the required molten metal when no weld nugget is formed at an interface; indeed, the required metal may need to be provided by inducing surface splashing at the electrode. The centre right-hand specimen in Fig. 5 contains two acicular projections raised from a single sheet of steel and set at an angle to it. The electrodes used for this are shown in Fig. 6.

Other Shapes

Special electrodes may be made to produce a wide variety of shapes, some of which are shown in Fig. 5. Where the shape is such that it may not be withdrawn directly from the cavity, a split electrode is required (Fig. 7). It is then necessary to clamp the two parts securely when in use.

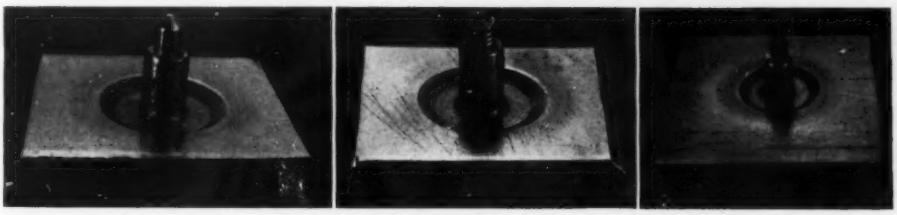
Inserts

By making suitable provision in the electrode cavity, inserts may be cast into studs. Copper, alumina, and steel inserts in steel studs are shown in Fig. 8. With suitable combinations of materials and with the lower part of the insert near the base of the stud, welding between stud material and insert can be achieved.

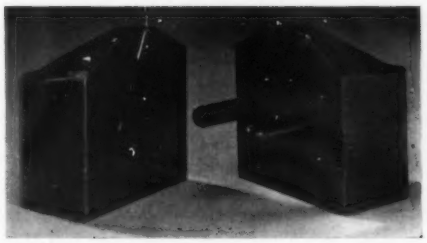


5—*Various shapes produced in steel by the resistance stud casting process*

6—*Electrode assembly for forming inclined spike*



8—*Steel studs with inserts of*: (a) *copper;* (b) *steel spring;* (c) *alumina*



7—*Split electrode used for forming studs of a shape which may not be directly withdrawn from the cavity*

Otherwise, as with non-metallic inserts, the joint is purely mechanical, but can nevertheless be very strong.

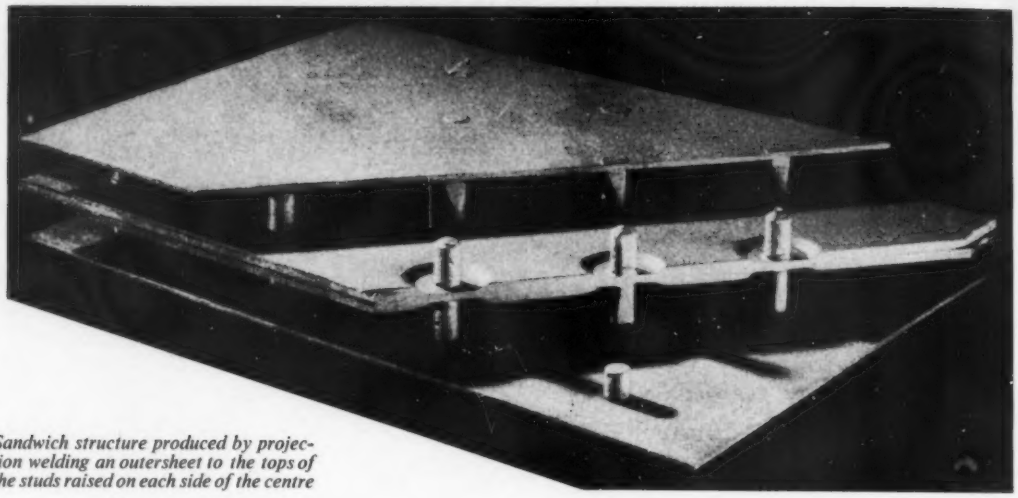
Projection Welding

The tops of studs may be suitably shaped (*e.g.*, conical) to allow a sheet of metal to be projection welded to them. In this way a sandwich structure of the type shown in Fig. 9 may be built up. There is no reason why the sandwich should not consist of several layers if required. Also, the process may be used to raise projections in thick material, enabling this to be projection welded without the need for machining the projection shapes.

Further Work

In addition to welding current and time, surface condition, material thickness, etc., which normally determine spot-weld size and quality, there are other factors to consider in electrical resistance stud raising. For instance, the volume of the stud and the electrode tip area obviously affect the indentation, *i.e.*, the amount the electrode sinks into the material. Also the combination of sheet thicknesses and the size of hole in the sheet adjacent to the electrode cavity are likely to be important variables. There is scope here for an investigation of the effect of the factors mentioned on the quality of the finished product. This is particularly important for materials susceptible to cracking or blow-holes and cavities.

Much work also remains to be done in developing the process for industrial applications. As for spot or projection welding many of the problems are likely to be associated with the design and manufacture of suitable jigs and electrode assemblies.



9—*Sandwich structure produced by projection welding an outersheet to the tops of the studs raised on each side of the centre*

Conclusions

(1) A method has been discovered by which protuberances may be formed on the surface of a metal article, using a spot-welding process.

(2) These protuberances may be in the form of a simple stud or may be more complicated in shape.

(3) The process may be applied to a wide range of ferrous and non-ferrous metals.

(4) Further work is required to investigate the effects of the variables and to perfect methods of applying the process in practice.

Acknowledgments

The author wishes to thank Mr. M. D. Hannah, to whom much of the credit is due for the initial discovery. He and Mr. D. H. Hillman also made substantial contributions to the subsequent developments described above.

(*Cont'd from p. 564*)

Commission XIII: FATIGUE TESTING

(*Chairman – H. de Leiris*)

Fatigue Failures in Service

Several more reports of service failures have been submitted and have been recommended for publication.

Influence on Fatigue Strength of Building-up Parts by Welding

This problem has proved to be very complex but is being actively investigated. The importance of annealing beads with subsequent runs has been demonstrated. Where there is a bending stress induced by rotation, and the base metal is mild steel, a technique used in the U.K. seems to ensure that the built-up part will be as strong as the original component. The strength of sprayed parts has also been investigated; it appears that the sprayed material adds nothing to the strength of the part in its prepared state before building up.

Butt Welded Joints

Having established satisfactory techniques of collaboration testing, resulting in close similarity of results from different laboratories, the Commission will now proceed with a more complex programme of tests.

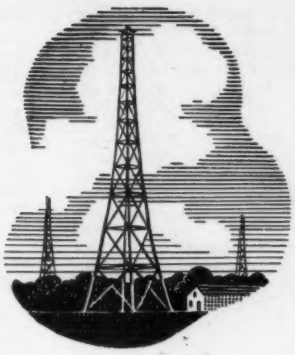
Interest has been shown in a method proposed by L. Locati whereby the fatigue limit may be determined from a single test piece. If the theoretical bases of the proposal are confirmed the method should be of great value in attempts to improve the fatigue strength of welded structures.

The Commission has already investigated some of these metals, including the creation of compressive stresses near the weak point of the structure, and the deposition at this point of special alloys with lower moduli of elasticity than the basic metal.

Frequency Distribution

In traditional fatigue testing the same upper and lower limits of stress are used for all the cycles applied. Since this rarely happens in practice the Commission is to collect information from various countries on the frequency distribution of stresses met with in different types of structure.

NEWS
and Announcements



News of the Institute and Branches
B.W.R.A. · Other Societies ·
and Industry

INSTITUTE ACTIVITIES

MEETINGS

Conversazione I.I.W. work in hand

A conversazione is to be held at the Institute from 4.0 to 8.0 p.m. on Friday, **4th December, 1959,** with the object of making the technical work of the International Institute of Welding better known to industry.

Among those to be invited will be the British delegates to I.I.W., representatives of their companies and firms, and representatives of other Industrial Corporate Members of the Institute.

It is hoped to arrange a few exhibits illustrating the work of the technical Commissions of I.I.W.

Postponement of Meeting

It is regretted that the Conversazione on I.I.W. work in hand, referred to above, has had to be postponed until sometime in February.

A further announcement will be made as soon as details are available.

Christmas Lecture to Young People

A Christmas Lecture to Young People, on the subject of "*The Magic Arc*", will be given by Professor Hugh O'Neill of University College, Swansea, on Tuesday, **5th January, 1960.**

The meeting will be held at the offices of the Institute at 34 Princes Gate, and will start at 11.0 a.m.

Members whose sons and daughters are between the ages of 13 and 16 are invited to apply to the Secretary for tickets.

Third Annual Lecture

Mr. W. J. John, Deputy Director of Naval Construction, Admiralty, has accepted the invitation of the President to deliver the Third Annual Lecture to the Institute on **3rd March, 1960.**

The subject of the lecture will be the influence of welding on the design of ships.

Spring Meeting 1960

The Spring Meeting of 1960 is to be held at Droitwich from 9th to 11th May. The general theme will be the novel welding processes and metal spraying.

NEWS OF MEMBERS

Obituary

The Council regret to record the deaths of:

Mr. **A. H. Scothern,** who had been an active member of the East Midlands Branch Committee for many years and had represented the Branch on the Council, on 8th September.

Mr. **A. H. Bent,** formerly of the English Electric Co. Ltd., on 24th March. Mr. Bent was one of the early members of the Midlands Branch of the Institute, and later he transferred his interests to the Wolverhampton Branch when it was formed out of the Midlands Branch. He took an active interest in Institute affairs, and for some years he served as a member of the General Purposes Committee.

Mr. **W. S. H. Hodges,** Chairman of Marcus H. Hodges & Sons (Engineers) Ltd., Exeter, on 7th October. (South Western Branch, Member 1932)

CONTRIBUTORS TO THE JOURNAL

John G. Poley, an Experimental Officer at the British Welding Research Association, was educated at Llandovery College, and afterwards spent two years on National Service in the electrical branch of Transport Command of the Royal Air Force, at the time of the Berlin Airlift. Subsequently he spent two years at the College of Technology, University of Manchester, studying electrical engineering. During vacations Mr. Poley worked as a student at the Margam Works of the Steel Company of Wales, in the Power Plant Department.

J. G. Poley

After leaving the University he was employed by the National Research Development Corporation (and later by D.S.I.R.) on a programme of research, at the Low Temperature Research Station at Cambridge, into the application of ion exchange resins and electro-dialysis cells to industrial purposes. Mr. Poley joined the B.W.R.A. in 1957 and works in the Welding Process Section, under Mr. A. A. Smith. He is particularly interested in both the fundamental aspects and the practical application of electric arc welding.

BRANCH NEWS

East Midlands

At the first meeting of the session, held at the Welbeck Hotel, Nottingham, on Tuesday, 13th October, a paper "*Some facts about iron-powder electrodes*" was given by Mr. A. B. Fieldhouse.

Mr. Fieldhouse said that iron powder electrodes were not new; experiments on their use had been started more than 25 years ago.

He said that less skill is required on the part of the welder than with normal types, because of the touch welding technique that was used. The heavy coating increases the deposition rate considerably, and it is possible to double the deposition rate of conventional electrodes.

An example was given showing that the time to deposit a cubic inch of weld metal with 6 s.w.g. iron powder electrodes was 99·3 sec, compared with 165·3 sec using conventional 4 gauge electrodes of the standard 217 type.

These electrodes do not strike an arc as easily as the rutile types, and care must be taken to keep the iron content fairly low, otherwise the electrode would feather.

Mr. Fieldhouse discussed the various types of iron powder electrodes available, and showed a slide comparing their qualities with those of corresponding conventional types.

Higher welding currents must be used to burn the heavier coatings, but the electrodes must still be capable of producing quality welds. A combination of hydrogen control and heavy coating will give good ductility over a large range of welding currents.

The lecture was concluded with a discussion on the application of the various types of these electrodes.

Afterwards, the Branch President, Mr. H. L. Palmer, proposed a vote of thanks, saying that the paper had given a very good start to the Branch lecture programme, and that if this standard is maintained throughout the season, the programme will be highly successful.

K.H.E.

East of Scotland

On the evening of Wednesday, 7th October a party of seventeen members and their friends visited the Works of the Pressed Steel Co. Ltd. at Paisley.

A tour of the Works was made and the welding of components for railway rolling stock was shown, using the latest techniques of arc welding. Everyone voted the visit a great success and the thanks of the Branch are extended to the Pressed Steel Co. Ltd., and in particular Mr. T. P. Stroud, Works Director, for making it possible.

The third meeting of the session took the form of a joint meeting with the Aberdeen Mechanical Society at Gordon's College, Aberdeen, on Friday, 16th October, when a paper by Mr. A. Bean entitled "*Recent Advances in Electric Welding*" was read by Mr. D. B. Tait, in the absence of the author who had been called overseas. The subject covered the advent of the latest types of manual arc welding electrodes, such as iron-powder, low-hydrogen, and low-alloy Cr–Mo. The latest types of fully automatic welding installations, using covered electrodes and covered electrodes with CO_2, both single arc and twin-arc, and also the latest in submerged-arc processes were dealt with. The advent of fully automatic equipment for horizontal and vertical seams was also mentioned. The types of semi-automatic continuous-wire inert-gas methods were also described, including the thin wire methods that are just being introduced in Britain. All these processes were amply illustrated with a good assortment of slides making for a most interesting and instructive evening.

A vote of thanks to the speaker was tendered by Mr. W. R. Craib, General Manager of Hall Russell & Co. Ltd., Shipbuilders, Aberdeen, and the thanks of the East Scotland Branch to the Aberdeen Mechanical Society was expressed by Mr. R. D. Berry, Hon. Secretary.

R.D.B.

Liverpool

Works visit

A visit to Associated Ethyl Co. Ltd. on 3rd October was organized by Mr. Pratt of the Company and led by the Chairman of the Branch, Mr. Ward. Mr. Davis, Past Chairman, acted as liaison representative.

A welding exhibition was keenly inspected and prompted valuable, interesting discussion. The Company uses special steels and alloys for vessels, pipes and linings to avoid the effects of corrosion, such as Hastalloy which is used as a lining to chemical vessels. The manual argon-arc welding process is used in fabricating this alloy. Silver, attached by silver solder brazing, is also being used as linings.

Joints are examined non-destructively by means of a portable X-ray set.

Members were handed a brochure which contained an outline of the plant, including a coloured diagrammatic guide.

Commemoration

Mrs. Griffin, widow of the late Treasurer, has offered a gift to the Branch in commemoration of her husband. The gift is in the form of a rose bowl and will make a pair with the Winged Lady "Berney" Cricket Trophy. It will be known as the "Bert Griffin" Trophy and will be the prize for a new competition between Wolverhampton and Liverpool Branches, yet to be decided.

Manchester

The programme for the new session opened on 7th October, with a lecture on "*The Importance of Welding Research for Industry*" by Dr. A. A. Wells, Deputy Director of the British Welding Research Association.

On the organization of research, Dr. Wells contrasted the arrangements in Britain with those in the U.S.A. on the one hand and with those in East European countries on the other. The freedom in the U.K. from patronage and pressure attending the conception and development of new processes was noteworthy, as was the range and number of projects being tackled.

The role of fundamental research was discussed in terms of its definition, of cases where it had resulted in problems being resolved, and of instances without it where failures had occurred. Work on welding problems had also provided the solutions to failures on non-welded structures. The Association's policy on applied research was to maintain a Development Department which would advise on problems at short notice and assemble case histories to apply to problems not resolvable by shop floor methods.

Discussion was concerned with communication between B.W.R.A. and industry, the many fields of work touched by B.W.R.A. in comparison with other Research Associations serving particular industries only, the financing of B.W.R.A. work, the role of committees in controlling or directing research, and liaison between the Association and research departments in industry.

Mr. T. Hill, in proposing a vote of thanks aptly summed up the proceedings as opening with world-wide considerations and descending to money and committees. He gave a warning of the dangers of insularity and stressed that a little guidance to industry was of much greater value than a lot of reports.

J.W.A.

The second meeting of the session, held on Wednesday, 21st October, was of special interest to designers and draughtsmen, who attended to hear Mr. H. B. Merriman's lecture entitled "*Welding and the draughtsman*".

The lecturer at the outset declared his intention of keeping the minds of his listeners free and uncluttered from frequent reference to welding symbols, and spoke of the need when tackling any problem in this rather complex field, to "design out" rather than to "design in".

Mr. Merriman dealt, in the main, with design procedure and problems arising in the pressure vessel field and, in particular, those relating to welded joints between stainless and carbon steels.

The lecture, which was amply illustrated by slides, was exceedingly interesting and it became very apparent, from the many questions and discussion, that the lecture had stimulated considerable interest among the audience of approximately 70 people.

A.C.W.

West of Scotland

The session opened with a meeting in Glasgow on 21st October when Dr. J. B. Marriott gave a lecture on "*Welding of pressure pipework for high- and low-temperature operation*".

The author reviewed present-day practices, and referred to the applications of the materials generally used: carbon steel, Cr–Mo alloys, austenitic stainless steels, nickel-alloy steels, notch-tough carbon steels, and the like.

The importance of avoiding fillet welds and other configurations which place the weld in shear was stressed. Since backing rings are disliked for this type of service, accurate alignment of the bores of the pipes being joined was shown to be necessary to provide defect-free full-penetration welds.

Various hand-hold and machine welding processes were described and their relative advantages for pipe welding were discussed; *e.g.*, the special precautions and techniques required for the argon-shielded processes have to be set against the quality of the weld obtained.

Difficulties inherent in joining dissimilar metals were mentioned and some permissible techniques were described.

After dealing with heat-treatment and inspection requirements, the review concluded with a discussion on the types of defect revealed by non-destructive testing and the weld quality allowed by certain codes of practice.

H.H.M.

Wolverhampton

The new session opened on Friday, 30th October, when 26 members attended the Old Wulfrunian's Club, Wolverhampton, to hear the Chairman's Address on "*The Ultrasonic Inspection of Butt Welds in Steel Pipe*" by Mr. S. K. Stokes.

Mr. Stokes stated that ultrasonic inspection was rapidly becoming accepted not only as complementary to radiography, but in some instances as an alternative. This applied particularly to heavy wall thicknesses, where sensitivity was rather greater than in the case of radiography. There was also the considerable advantage of speed, even though up to four scans were necessary to determine the position, size, and nature of any particular flaw.

To achieve the degree of reliability necessary for such work, a number of points have to be watched, and Mr. Stokes mentioned preparation and marking out, selection of probe, and calibration of equipment, as being particularly important.

In regard to preparatory work, both surfaces should be cleared of rust, scale, spatter, and other imperfections that prevent free movement of the probe, but grinding off the weld reinforcement should not normally be necessary. The limits of scanning on each side of the weld are usually $2t \tan \alpha$, and these should be clearly marked by chalk lines on the job, together with subdivision marks for ease of reporting and

locating defects. Before carrying out examination of the weld itself, it is necessary to check the parent metal on either side of the weld for thickness and laminar inclusions, since misleading results might otherwise be obtained (*e.g.*, a laminar inclusion might shadow a weld fault).

Selection of the probe is particularly important, and Mr. Stokes suggested that the versatility of ultrasonic equipment varies directly as the square of the number of probes available. The best angles to use were 60° (up to 1½ in. thick plate) and 45° (for greater thicknesses), measured normal to the plate surface. A single probe method is usually preferable to a double probe system, since operator fatigue is considerably reduced, and because on a curved surface it is difficult to maintain an adequated egree of surface contact with two probes.

Crystal diameter must be selected to suit the particular frequency chosen, and for 2½ Mc/sec a 15 mm diameter will give a half-angle spread of 8° in steel. A smaller crystal will give a wider beam and will lead to loss of accuracy in estimating the position of a flaw.

The wavelength corresponding to 2½ Mc/sec is approximately 1 mm, and flaws approximately half this size may be resolved. However, for coarse grained materials considerable scatter will occur, and in this case it is necessary to use a lower frequency (greater wavelength).

A number of reference blocks should be available for the calibration of the equipment. For calibrating the time base the B.W.R.A. block is considered to be then most suitable—this will relate the time of travel of the pulse to the distance travelled in the steel. A frequent check against this block is advisable to ensure that there has been no drift from the original settings.

The amount of energy reflected from a flaw depends not only on its size but also on its shape and orientation. The four basic shapes of flaw are corners (K), planar (P), spherical (S), and cylindrical (C) and test blocks have been designed to simulate these for calibration purposes. K-type defects are represented by milled grooves; P-type by flat bottomed holes drilled parallel to the ultrasonic beam; S-type by hemispherically bottomed holes drilled parallel to the beam; and C-type by holes drilled parallel to the plate surface. Extensive experience and analysis is necessary to determine the variance in pulse height between actual flaws and these simulated flaws.

Mr. Stokes mentioned some of the difficulties that were encountered in ensuring that the amount of energy entering the specimen was constant. Various coupling fluids have been tried, but heavy grease was usually the most effective medium. Owing to curvature of the pipe wall and other considerations, variations in films thickness could not be prevented, and he strongly advocated the use of some form of surface contact monitor. He also suggested that the performance of operators should be constantly checked against known specimens.

The meeting concluded with two interesting films showing various application of welding in tubular structures. A vote of thanks and an expression of good wishes for his term of office were proposed and seconded by two past chairmen of the Branch, Mr. E. Flintham and Mr. C. Spencer.

B.K.B.

NEWS FROM INDUSTRY

Reduced electrode prices

The English Electric Co. Ltd. have announced that the price of all their mild steel electrodes has been reduced by 5%. This reduction covers twelve types of electrode: the all-position Enrox, Vohees and Vertees; the iron powder types Speedees Hermees and Pressurees I.P.1; the Lowhees, Deepees, Herculees 35, Pressurees, Fillerees and the new electrode Weldees.

Canadian order for walking dragline

A contract worth 1½ million dollars has been won in the face of fierce American competition by Ransomes and Rapier Ltd. of Ipswich, who have received an order from Calgary Power Ltd., Alberta, for a large electrically driven walking dragline. This is the first time a contract for this type of machinery has been placed in Great Britain for delivery to the North American Continent.

The Rapier W1350 will weigh 1400 tons and will be equipped with a 33 cu.yd bucket capable of carrying 50 tons of material at a time at a radius of 215 ft. The dragline will be manufactured at Waterside Works and after dismantling will be shipped in suitable units to the assembly area at Wabamun, near Edmonton, Alberta.

The very low temperatures in which the dragline must work in the winter-time sets many interesting problems of design and construction. Special steels will be used to meet these conditions.

Machine tool expansion

A five-year development scheme has recently been completed at the Possilpark Works of Hugh Smith & Co. (Possil) Ltd. This has allowed the company to introduce new high performance machine tools which will enable them to develop new and improved designs of their well-known plate-bending, straightening, flanging and other machines for heavy fabrication.

Among the new machine tools is the latest Asquith No. 6 travelling head milling, facing, boring and drilling machine, which has a table area of 50 × 20 ft and can be used for boring up to a maximum height of 12 ft. The machine is installed in an erection bay 250 ft long and 55 ft wide with 40 ft clear height below the hook of a 100-ton Babcock & Wilcox crane.

In addition to this bay the development scheme has covered the provision of a 200 ft long material storage bay, new drawing offices, and modernized office accommodation.

Exhibition of air-cooled diesel engines

A comprehensive exhibition of contractors' plant and machinery, all powered by Lister air-cooled diesel engines, was held at the Dursley factory of R. A. Lister and Co. Ltd. at the beginning of October. Several stands displayed up-to-date welding sets, including the Murex 300/400 amp mobile single-operator set, and the 300 amp and 400 amp portable welding machines of Welding Industries Ltd.

The many engineers who visited the exhibition also made a comprehensive tour of the factory where the engines are produced.

Welding school for nuclear projects

To meet the stringent specifications imposed on all welding for nuclear energy projects, the John Thompson Group has inaugurated special courses for its employees at its new welding school in Wolverhampton.

Progressive courses are held and operators are constantly tested to insurance company specifications. Correct procedure is vitally important in nuclear energy applications, all pipe welds being subjected to X-ray and gamma-ray examinations.

Equipment and oxygen are supplied to the school by British Oxygen Gases, Ltd.

Aluminium street lighting columns

Awards were recently made to the prize-winners of an Open Competition organized by The Aluminium Development Association for the design of trunk road and non-trunk road lighting columns made of aluminium.

New erection shop of Hugh Smith & Co. (Possil) Ltd.

The prize-winners were Mr. J. Howe (A.E.I. Lamp & Lighting Co. Ltd.), Mr. J. B. Dwight (University of Birmingham), Mr. F. J. B. Rowley (College of Art and Industrial Design, Newcastle), Mr. S. L. Devlin (Royal College of Art, London). The design of the first winning entry was for a tapered triangular column made up of HE9–WP extrusions joined by epoxy resin adhesives. Welding was specified for the fabrication of the gear chamber door.

The second entry was for a 4-sided tapered shaft in pressed NS4 sheet and LM6 casting. The third design used triple tubes in HV9–WP, enclosed at the base by three sheet panels of NS3–H, all the joints being made by welding.

NEW PLANT AND EQUIPMENT

Welding helmets

Safety Products Ltd. of Redhill have recently introduced a new range of 'Superweld' helmets and headshields, 800 Series. The shell of the helmet is moulded in one piece from vulcanized fibre and is fitted with a rachet strap and lens aligner to give positive stops for overhead, normal, and down welding positions. Smooth action is given by nylon bearings, and a moulded rubber window housing provides light and shock proofness to the replaceable lenses.

The accompanying illustration shows the vital importance of safety devices in metallurgical and fabricating industries. It shows a 'Pulsafe' safety goggle fitted with a clear 'Triplex' lens which had been splashed by molten aluminium at an estimated temperature of 700°C. The lens did not crack and the wearer received only slight burns on the head and hands.

Lightweight welding blowpipe

The 'Light Weight Saffire' is a new blowpipe added to the range of equipment specially developed by British Oxygen Gases, Ltd., for welding sheet metal and for light welding repairs. The blowpipe, completely assembled to include one of the standard range of nozzles, weighs only 9½ ounces. It has forward-mounted controls for easy adjustment, and is 13½ inches long. It has a new type of mixer assembly specially designed to provide a stable flame and resistance to back-fires over the whole working range. The range of six nozzles permits welding of sheet steel up to $\frac{5}{32}$ in. thick, but three additional nozzles are available for thicknesses up to $\frac{1}{16}$ in.

Welding equipment for thin materials

A further addition to the small range of equipment now available for welding these materials has been made by the introduction of the 'Sigmette' gun by Quasi-Arc Ltd. A prototype was exhibited at the South London Branch conversazione (*BWJ*, November, p.550). The Sigmette equipment is based on the established Sigma process, using a continuous coil of bare wire electrode and shielding by argon gas or by CO_2. Metal transfer is in globular form, as distinct from the spray type of transfer normally associated with Sigma welding.

Welding of all ferrous and non-ferrous materials can be carried out in every position, including vertical and overhead. Only the gun needs to be carried to the work, so that the operator can weld comfortably in confined spaces or in areas remote from power and gas supplies without having to move heavy equipment.

The welding gun weighs just over 3 lb, and a spool carrying either 1 lb of aluminium wire of 2½ lb of ferrous wire is carried on the gun itself. Welding can be carried out for periods of up to ¾ hr on one spool of wire.

The wire is positioned initially by an inching button in the base of the handle. Pulling the trigger starts the gas flow and initiates a slow wire feed. As soon as the arc strikes the wire is fed at full speed, which is adjustable by a single knob on the voltage control unit.

The gun is continuously rated at 125 amp for 0·030 in. wire and at 200 amp for $\frac{5}{64}$ and $\frac{1}{16}$ in. wires, the three sizes it can accommodate. A medium-speed wire-faced motor is fitted as standard, but high-speed or low-speed motors can be supplied for specialized work using 0·030 or $\frac{1}{16}$ in. wires.

CORRECTION

Ultrasonic testing of welds

In the paper by D. O. Sproule (*BWJ*, October 1959, p. 473) an error was made in the titling of the block for Fig. 7. The item shown as 'Main Attenuator' should be the 'Main Amplifier'.

DIARY

1st Dec.—Metal and Plastic Coatings Association—Annual General Meeting.

2nd Dec.—Manchester—"*Questions about welding*" answered by panel of F. Koenigsberger, E. J. Heeley, R. Bushell, E. H. Lee (College of Technology, 7.15 p.m.)

3rd Dec.—Birmingham—Annual Dinner (Grand Hotel, Birmingham)
North Eastern (Tyneside)—"*Welding in the production of marine oil engines*" by J. A. Dorrat (Mining Institute, Newcastle on Tyne, 7.0 p.m.)

4th Dec.—Institute of Welding—Conversazione: "*I.I.W. work in hand*". **Now postponed.**

5th Dec.—North Eastern (Tyneside)—Annual Dinner (Old Assembly Rooms, Newcastle)

7th Dec.—West Wales—"*Selection and uses of arc-welding processes*" by E. Flintham (Neath Technical College, 7.0 p.m.)

7th-11th Dec.—School of Welding Technology—Course D.5/2 "Inspection and testing".

8th Dec.—Eastern Counties—"*Welding and the draughtsman*" by H. B. Merriman (Ipswich)
East Wales—"*Selection and uses of arc-welding processes*" by E. Flintham (Llandaff Technical College, Cardiff, 7.0 p.m.)
Liverpool—"*Gas-shielded arc processes with consumable electrodes*" by D. B. Tait (College of Technology, Byrom Street, 7.30 p.m.)
South Western—Meeting to be arranged (Radiant House, Bristol, 7.15 p.m.)
North London (Slough Section)—"*Low temperature brazing and welding*" (Community Centre, Slough, 7.0 p.m.)

9th Dec.—South London—"*Characteristics of welding plant*" by J. C. Needham (54 Princes Gate, S.W.7, 7.30 p.m.)
Preston—"*Metal spraying developments*" by W. E. Ballard (Harris Technical College, 7.15 p.m.)

10th Dec.—Leeds—Annual Dinner (Hotel Metropole)
Southern Counties—"*Welding in aluminium*" by H. C. Constantine (Technical College, St. Mary's, Southampton)

11th Dec.—Birmingham—"*Reactions and metal transfer in arc welding*" by D. R. Milner (Grand Hotel, 7.30 p.m.)

14th Dec.—Sheffield—"*Fabrication of heavy steel components*" by W. Plews (Joint meeting with Sheffield Branch of the Institution of Production Engineers) (Grand Hotel, 7.15 p.m.)

15th Dec.—East Midlands—"*Requirements and general aspects of manual arc-welding plant*" by R. H. Boughton (Victoria Station Hotel, Nottingham, 7.15 p.m.)
Wolverhampton—"*Welding and the draughtsman*" by H. B. Merriman (College of Technology, Wolverhampton, 7.30 p.m.)

16th Dec.—North London—Visit to Angel Road Works of British Oxygen Gases Ltd
West of Scotland—"*Welding of rolling stock at British Railways*" by G. Walton (Institute of Engineers and Shipbuilders, Glasgow C.2, 7.0 p.m.)

17th Dec.—Leeds—"*The 250-ft diameter radio telescope at Jodrell Bank*" by C. N. Kington (Great Northern Hotel, 7.30 p.m.)

18th Dec.—South Western—Annual Dinner (Berkeley Restaurant, Bristol)

1960

4th Jan.—Sheffield—Annual Dinner (Royal Victoria Hotel)

4th-15th Jan.—School of Welding Technology—Course D.27 "Practical ultrasonics for operators"

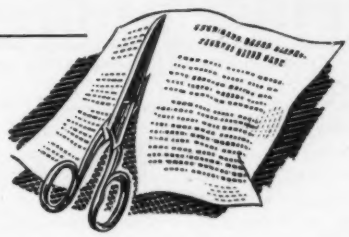
5th Jan.—Institute of Welding—Christmas Lecture to Young People—"*The Magic Arc*" by Professor H. O'Neill (54 Princes Gate, 11.0 a.m.)

5th-7th Jan.—Institution of Mechanical Engineers—Symposium on recent mechanical engineering developments in automatic control.

6th Jan.—Manchester—"*Inspection and interpretation of welding codes*" by C. Atkinson (College of Technology, 7.15 p.m.)

7th Jan.—North Eastern (Tyneside)—"*Welding of the boilers for Bradwell atomic power station*" by P. E. M. Jones and K. Twigg (Mining Institute, Neville Hall, Newcastle, 7.0 p.m.)

Current WELDING LITERATURE



Book Reviews

Additions to the Institute Library

Trade Publications

CONTENTS OF PERIODICALS RECEIVED

This section is intended to give a survey of the current welding literature received by the Institute of Welding Library. The contents lists are not exhaustive; only the main articles in welding journals are listed, and reprints from other journals and short notes are generally excluded. In addition, welding articles from other periodicals are listed. Abstracts of welding literature are given in the Bibliographical Bulletin of Welding and Allied Processes, *published by the International Institute of Welding, and details of this may be obtained from the Secretary of the Institute of Welding.*

Welding Journals

Australian Welding Journal, 1959, vol. 2, May

Fuel for thought—a comparison of the merits of L.G.P. and acetylene, A. E. Wilson (7–9)

Welding processes combine in the manufacture of rock boring tools (14)

Static brittle-fracture initiation yield at net stress 40% of yield, C. Mylonas and others (21–26)

Automatic welding on short run production, M. T. Pritchard (27–29)

Canadian Welder, 1959, vol. 50, July

Characteristics of high-current DC welding power sources, R. L. Stuffen (10–12)

Fully automatic welding plant, D. Ewan (14–15)

Aluminium pipeline welder (19–20)

Ciencia y tecnica de la Soldadura (Spain), 1959, vol. 9, May–June

Characteristics of direct current generators for arc welding, A. Carrer

Notes on the use of radiographic inspection in naval construction, F. S. Lalhe and C. G. Maurino

Examples of welded constructions in the fabrication of apparatus for the chemical industry, R. Sohngen

Welding as an important factor in industrial progress, B. L. Williams

Przeglad Spawalnictwa (Poland), 1959, vol. 11, August

Submerged arc building up with bronzes, S. Dobke

New automatic head for submerged arc welding, S. Sokolowski

Welding of pipelines, S. Piwowar

On relationship between strength and dimensions of a spot-welded joint, E. A. Juffy

Schweissen und Schneiden (Germany), 1959, vol. 11, August

Experience in the application of DIN 8560 to the testing of welders, H. Fiehn and K. Teske (310–315)

Strength of welded connections on cylindrical containers, H. Heusler (315–138)

Semi-mechanical welding with CO_2 protection in the manufacture of chemical and equipment, R. Faulstich (319–322)

Schweisstechnik (Germany), 1959, vol. 9, August

Appeal to all repair shops. "Submerged arc welding contra wear and tear", Gunther (273–274)

Test results on welding air condition during CO_2 welding, G. Hebold (274–275)

Comparison of working time and costs arising in semi-automatic CO_2 welding and manual metal-arc welding of structural members, G. Hebold (275–277)

Investigation of the depth of penetration and its influence on the fatigue strength of manual fillet welds a = 4 mm as a function of electrode diameter, H. Michel *et al.* (281–283)

Welding conditions, operation techniques, quality factors and economical characteristics for semi-automatic CO_2 welding, H. Berger and H. Rosenkranz (284–294)

Characteristic values and capacity problems of the welding technique in shipbuilding, A. Fichte *et al.* (295–299)

On the application of high frequency discharge and electron torch in the welding technique, G. Tybus (299–302)

Hard-facing against wear and tear with the aid of submerged arc welding devices using hollow cables (UPHK-Equipment), H. Meyer (305–306)

Repair welding of two sliding cylindrical valve casings, A. Vogt (307–308)

Welding and Metal Fabrication, 1959, vol. 27. July

Pipe welding and constructional work (264–274)

Joining dissimilar metals, J. G. Young and A. A. Smith (275–281)

Storing methane at −260°F (282–284)

The present position of copper welding, L. Bernhardt (285–286)

The plasma arc torch (287–290)

Research at Aldermaston (291)

A review of some recent developments in industrial radiography, R. Halmshaw (292–297)

Welding Engineer (U.S.A.), 1959, vol. 44, August

Welding provides the key for the door to America's nuclear reactors (27–28)

Welding positioners aid manufacturer in precision production of jet aircraft (29)

Techniques for torch brazing aluminium, H. E. Adkins and R. A. Ridout (30–32)

How to get the most from semi-automatic welding machines (33–35)

Welded rail, concrete ties win German approval, H. J. Miller (36–37)

Welding figures prominently in 7-year plan (40, 42, 44)

Missile brazing time cut by new facility (45)

Welding Design and Fabrication (Formerly *Industry and Welding*), (U.S.A.) 1959, August

Russia's new 7 year-plan calls for 40% more automatic welding 7,500-ton press ram uses Al, 500 lb aluminium bronze overlay, V. Nigriny

Are spot and seam welds practical in tension? Peel tests say yes

Know your filler metals, part 2, O. T. Barnett

Use low cost heat straightening, L. J. Larson

A breakthrough for tantalum welding, B. Payne

Design hints for using welded tubing

What designers should know about welded steel construction, C. I. Orr

New "W" joint eliminates costly tooling

Welding Journal (U.S.A.), 1959, vol. 38, August

Recent metal-removal developments with compressed-air carbon-arc process, M. D. Stepath, H. B. Nelson and W. J. Coughlin

Welding of fuels and controls for Dresden Nuclear Power Station, C. N. Spalaris and J. W. Weyers

Welded clad-steel pipe for reactor construction, W. H. Funk

Practical welding procedures, S. I. Roberts and C. E. Cole

Practical approach to determine weld size, O. W. Blodgett

Metallurgy of bonding in brazed joints, N. Bredzs and H. Schwartzbart

Effect of specimen geometry on Charpy low-blow transition temperature, G. M. Orner

Isotope techniques for inspection and evaluation of ship welds, E. L. Cricuolo

Process welding of nodular and gray-iron castings, B. Townshend and E. O. Porter

Welding of reinforcing bars for concrete construction, J. F. Rudy, F. Suyama and H. Schwartzbart

Zvaranie (Czechoslovakia), 1959, vol. 8, August

Welding problems discussed during the Plenary Session of the Central Committee of the Communist Party of Czechoslovakia (225–226)

Properties of the new Ni-Cr type boron deposit-weld alloy, K. Lobl (227–229)

Capillary soldering in furnaces with shielding atmosphere, V. Ruza (230–236)

Welding of Toros steel, A. Brebera (236–238)

Exhausting and air-conditioning in welding shops (239–245)

Some notes on position welding, M. Mesaros (245–247)

Carbon slotting prevails, J. Chlubny (247–248)

Other Journals

Electric arc welding and its industrial applications, B. N. Mohindra (*Journal of the Institution of Engineers* (India), 1959 vol. 39, June, pp. 1007–1017)

How Germany uses surface flame-hardening—1, W. A. Hawkins (*Metal-working Production*, 1959, vol. 103, 28 Aug., pp. 1311–1318)

The use of coated steel sheets in buildings, F. H. Smith (*Sheet Metal Industries*, 1959, vol. 36, July, pp. 497–510)

Aluminized steel—its properties and uses, K. G. Coburn (*Metallurgia*, 1959, vol. 60, July, pp. 17–20)

Plastics coatings for corrosion protection (*Engineering Materials and Design*, 1959, vol. 2, August–September, pp. 414–416)

Improving wear resistance by hardfacing by welding, E. N. Gregory (*Engineering Materials and Design*), 1959, vol. 2, August–September, pp. 425–429)

Effect of molybdenum spraying on adhesion of metals, D. Birchon (*Engineering Materials and Design*, 1959, vol. 2, August–September, pp. 436)

Flame hardening in use: the Peddinghaus Process (*Engineering*, 1959, vol. 188, 21 August, pp. 77–78)

Non-destructive testing in electrical engineering, D. J. Griffiths (*English Electric Journal*, 1959, vol. 16, June, pp. 24–39)

Some model tests on multi-storey rigid steel frames, M. W. Low (*Proceedings of the Institution of Civil Engineers*, 1959, vol. 13, July, pp. 287–298)

Developments in heat treatment—3: Controlled atmosphere annealing, J. McMullen (*Metalworking Production*, 1959, vol. 103, 28 August, pp. 1325–1327)

Stress relief of mild-steel welded structures, S. J. Watson (*Metropolitan-Vickers Gazette*, 1959, vol. 30, May, pp. 137–139)

Protection against eye accidents, J. A. Campbell (*Engineer and Foundryman*, (South Africa), 1959, vol. 24, May, pp. 47–52)

BOOKS AND PAMPHLETS

AMERICAN SOCIETY FOR TESTING MATERIALS. *Specifications for steel piping materials.* Philadelphia, A.S.T.M., April 1959. (Price $6.00)

AMERICAN WELDING SOCIETY. *1958 Supplement to the A.W.S. Bibliographies* (A7.0–58). New York, A.W.S., 1959. (Price $1.50)

GROVER, La Motte. *Strength of arc-welded joints. The arc-welding processes.* Intended for use as a supplementary text in an elementary course on strength of materials. New York, N.E.M.A., 1959. (Price 25 cents)

TRADE CATALOGUES

Philips arc welding plant: Additions to transformer range. Philips Electrical Ltd., London.

Fararc 200: New Autospot 4·8 kVA machine. Portable Welders Ltd., Buckingham.

R.F. induction heating. Radyne 1 kW induction heater. 1 kW and 3½ kW induction heaters by Radyne. 6 kW induction heater by Radyne. Radyne 15 and 25 kW induction heaters. R.F. induction heater accessories by Radyne. Radyne induction heating handling equipment. Radyne laboratory furnace. Radyne News Sheets. New 10 kW R.F. induction generator. Radyne "Depositron". Revolutionary wire tinning method prevents splayed ends. "Stellite" hardfacing. Vacuum fusion gas-analysis of metals. 2 to 5 Mc/s R.F. generators for silicon refining. Radyne Review No. 1. Induction heating in the motor industry. Radyne Review No. 2. Zeta and Radyne. Radyne Review No. 3. Induction hardening. Radio Heaters Ltd., Wokingham.

Tippex welding powders: the perfect weld for tool tipping. Sagma Ltd., London.

Low temperature brazing of tungsten carbide tool tips. The repair and joining of aluminium casting alloys. "Thessco" silver solders LX 13. and LX 7 "Thessco" silver solders MX 8 and MX 0. "Thessco" silver solders MX 18 and MX 12. "Thessco" silver solders, Phosphalloy 1 and 2. Sheffield Smelting Company Ltd., Sheffield.

Electro-gas for soldering, brazing, annealing, hardening. High frequency induction heating equipment. Resistance heating: the rapid easy way of soldering. Standard Telephones and Cables Ltd., Heat Treatment Group, Sidcup, Kent.

Sifbronze. Sifbronze equipment, regulators, blowpipes, goggles. Sifbronze oxy-acetylene welding products: price list. Sifbronze oxy-acetylene welding products: specifications. Suffolk Iron Foundry (1920) Ltd., Stowmarket.

Fully automatic shape-cutting machine now available. New Oxweld regulators eliminate gauges. Powder gives cutting flames a flying start. Union Carbide International Co., New York.

Automatic flux control in gas welding. Weldcraft Ltd., Croydon, Surrey.

Brazing carbide tipped tools by the high frequency induction heating process. 3 kW induction heating equipment. 7½ kW induction heating equipment. Mesh belt conveyer furnaces for continuous bright annealing; brazing, sintering, etc. Wild-Barfield Electric Furnaces Ltd., Watford, Herts.

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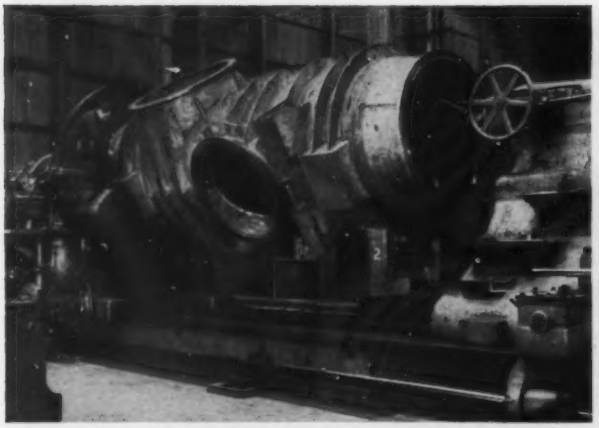

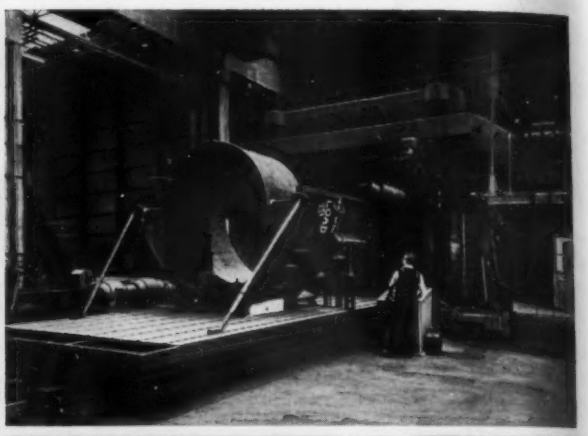

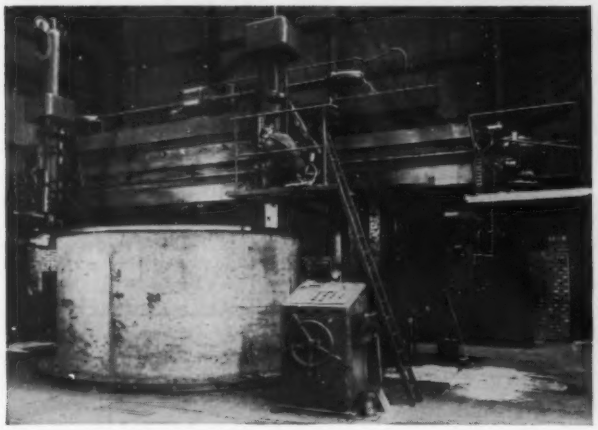

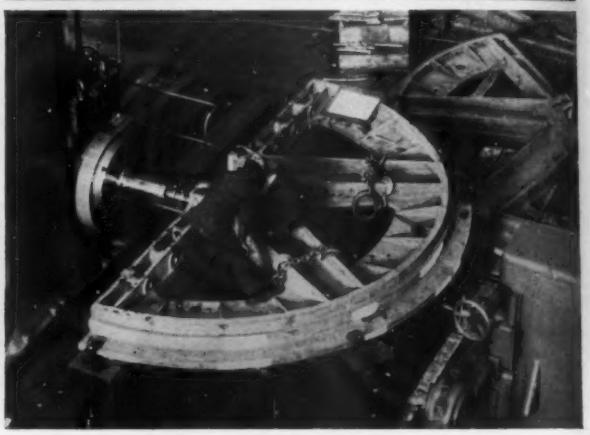

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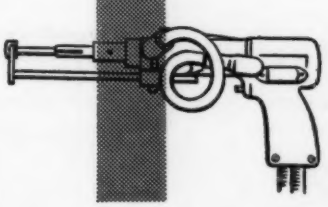

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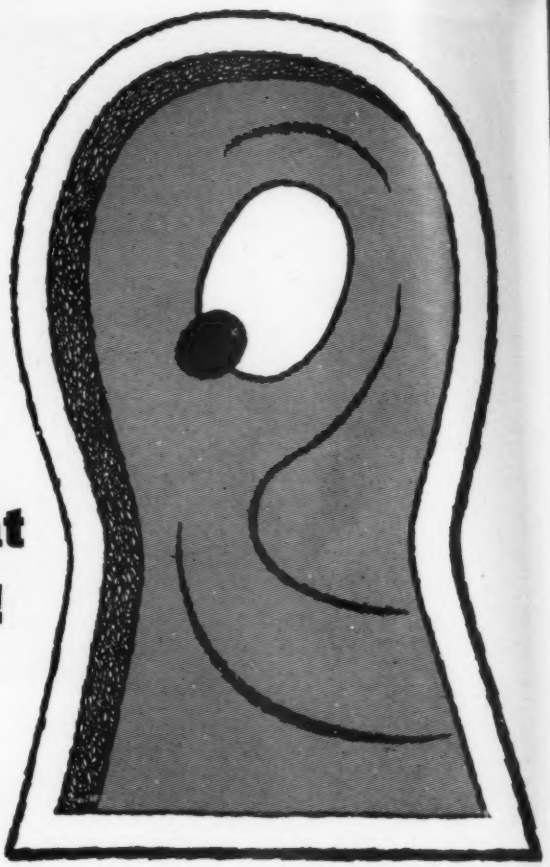
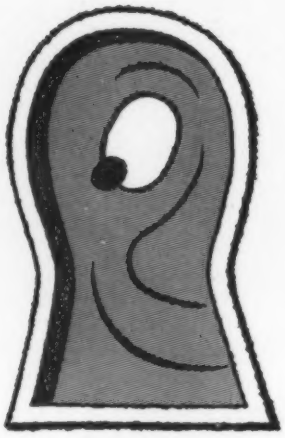


You'd be surprised what MAPEL can see!



. . . especially if you're worried about the efficiency of your welding.

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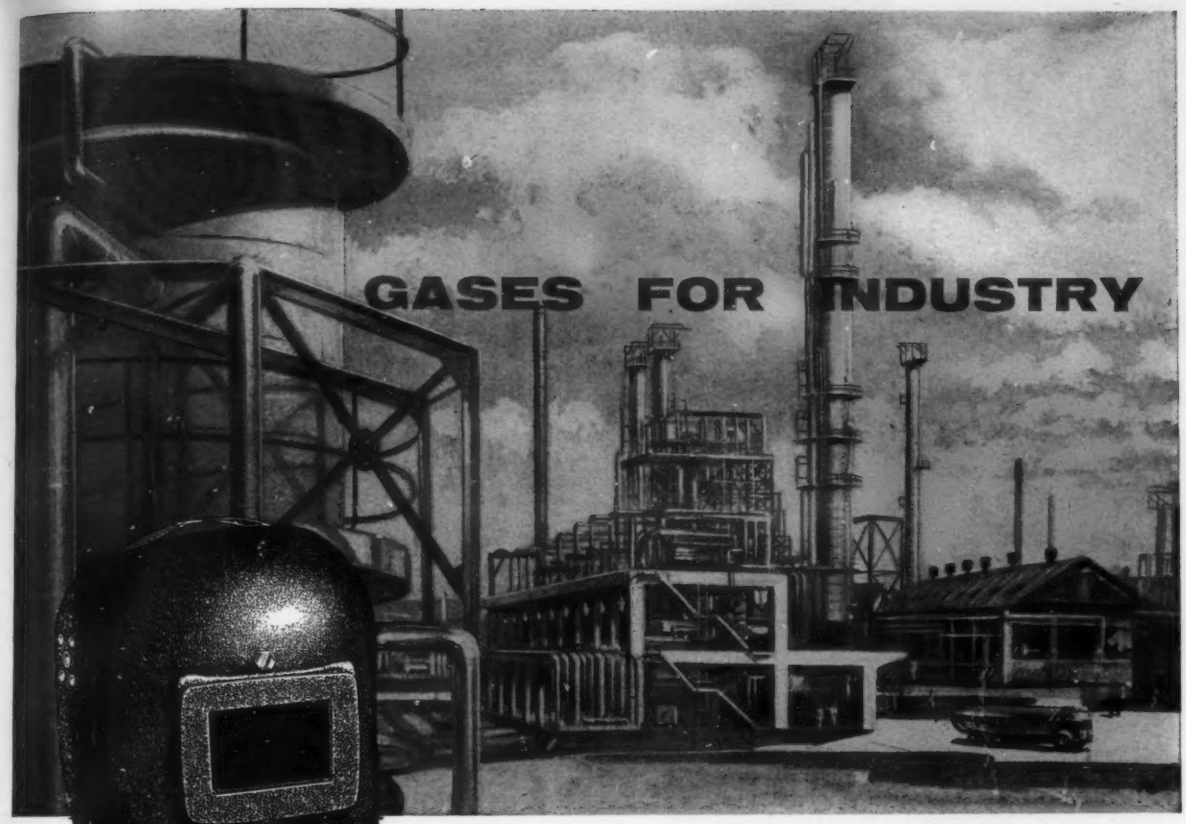

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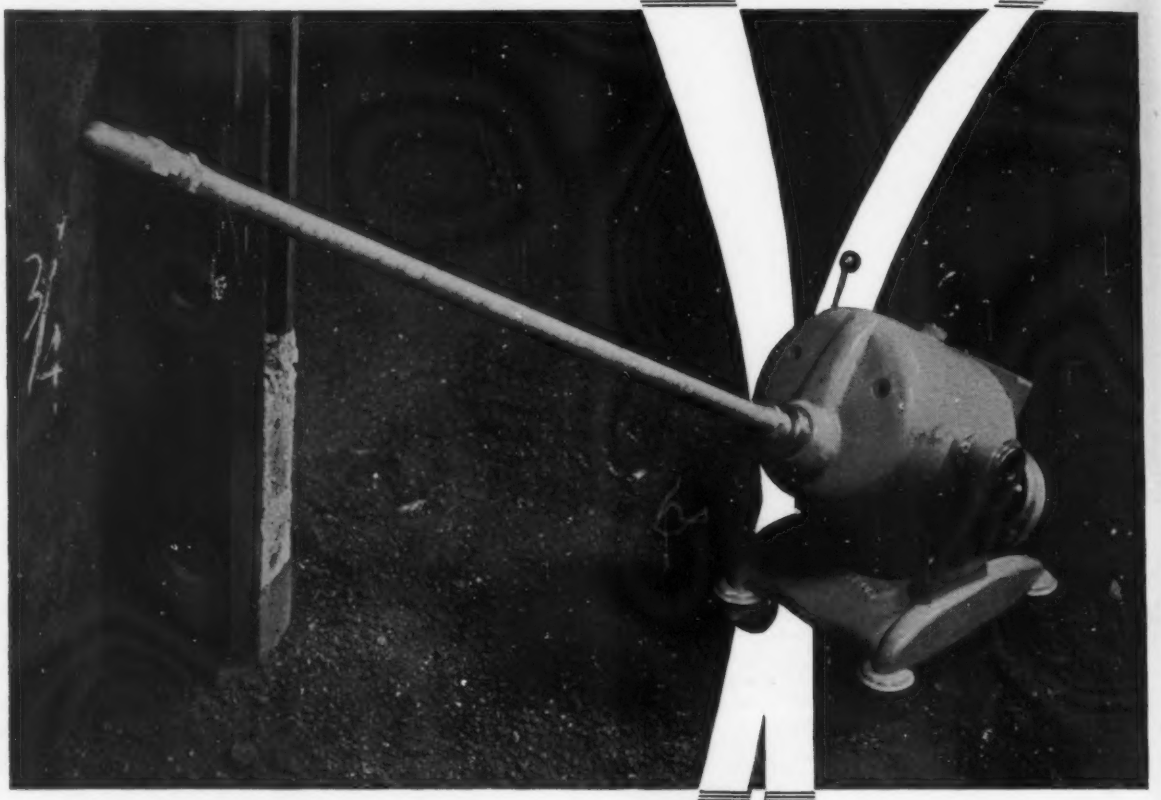

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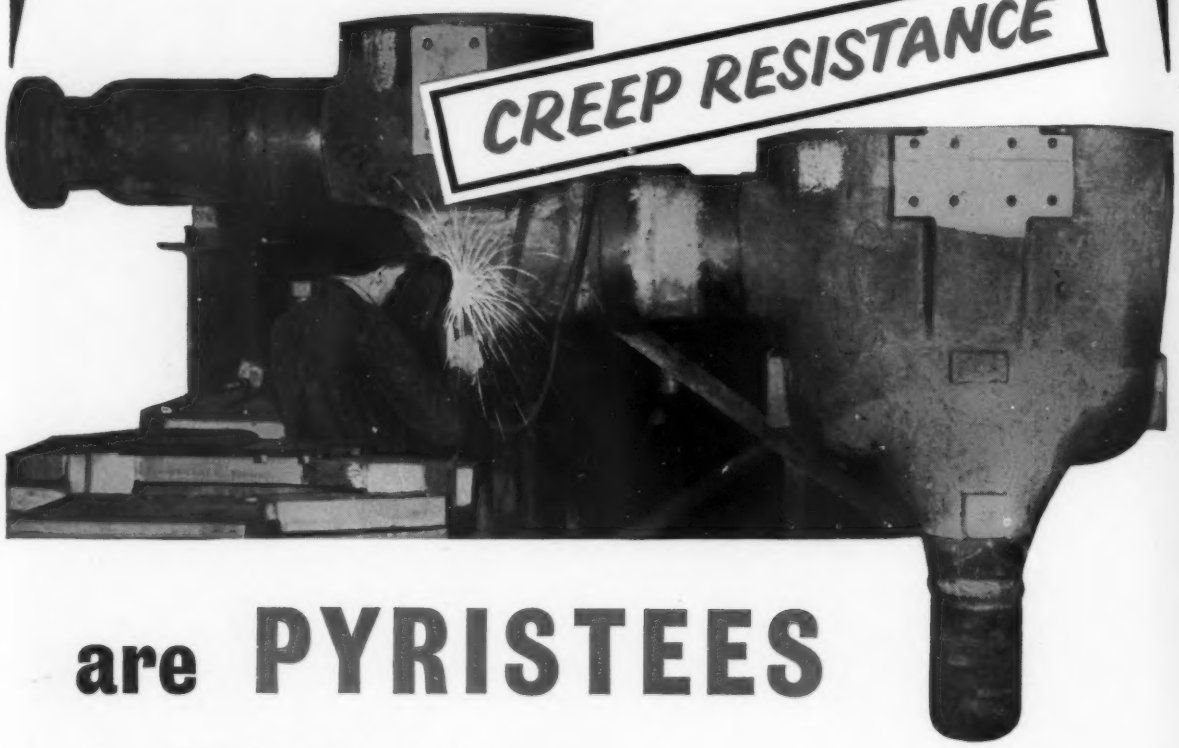
The electrodes for



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PYRISTEES electrodes were used exclusively for joining these two steam chests of chrome-molybdenum-vanadium-tungsten alloy steel, which are in service at a British power station with turbines operating at 1500 p.s.i.g. 1050°F.

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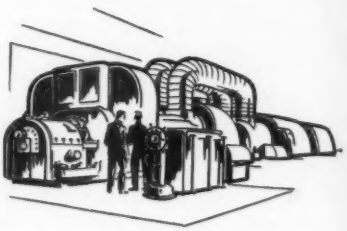

Send for publication WA/147 to The English Electric Co. Ltd., Welding Electrode Division, Clayton-le-Moors, Accrington, Lancashire.

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AEI ELECTRONICS DATA SHEET
Subject IGNITRONS — RATINGS

Welder types

Types	Maximum Demand* (kVA)	Maximum average* anode current (Amps.)	Temperature control
BK 22	450	15	—
BK 24	1200	140	—
BK 24A	1200	140	Integral
BK 24B	1200	140	Clamp on
BK 34	2400	355	—
BK 34A	2400	355	Integral
BK 34B	2400	355	Clamp on
BK 42	600	56	—
BK 42A	600	56	Integral
BK 42B	600	56	Clamp on
BK 66	300	22·4	—

* Ratings are for welder control service and refer to two valves in inverse parallel at any voltage from 250-600v. r.m.s.

Rectifier types

Type	Maximum peak voltage (Kilo volts)	Maximum average current at peak voltage (Amps.)
BK 44	2·1	75
BK 46	2·1	150
BK 56 †	20·1	150

† Tentative ratings.

ASSOCIATED ELECTRICAL INDUSTRIES LIMITED

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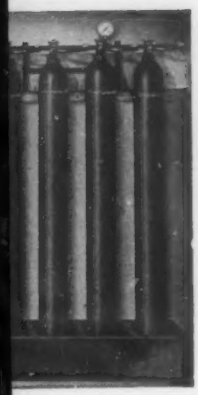
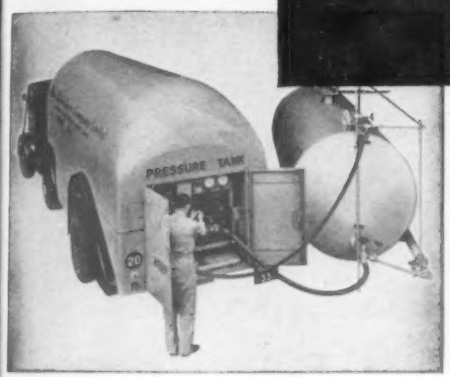
A.5447

Photograph illustrating the FUSARC/CO_2 process by courtesy of Quasi-Arc Limited





The use of low pressure CO_2 gas as an inert shield in the welding of steels is increasing. CO_2 is not only cheap—it enables high quality welds to be made in the shortest time.

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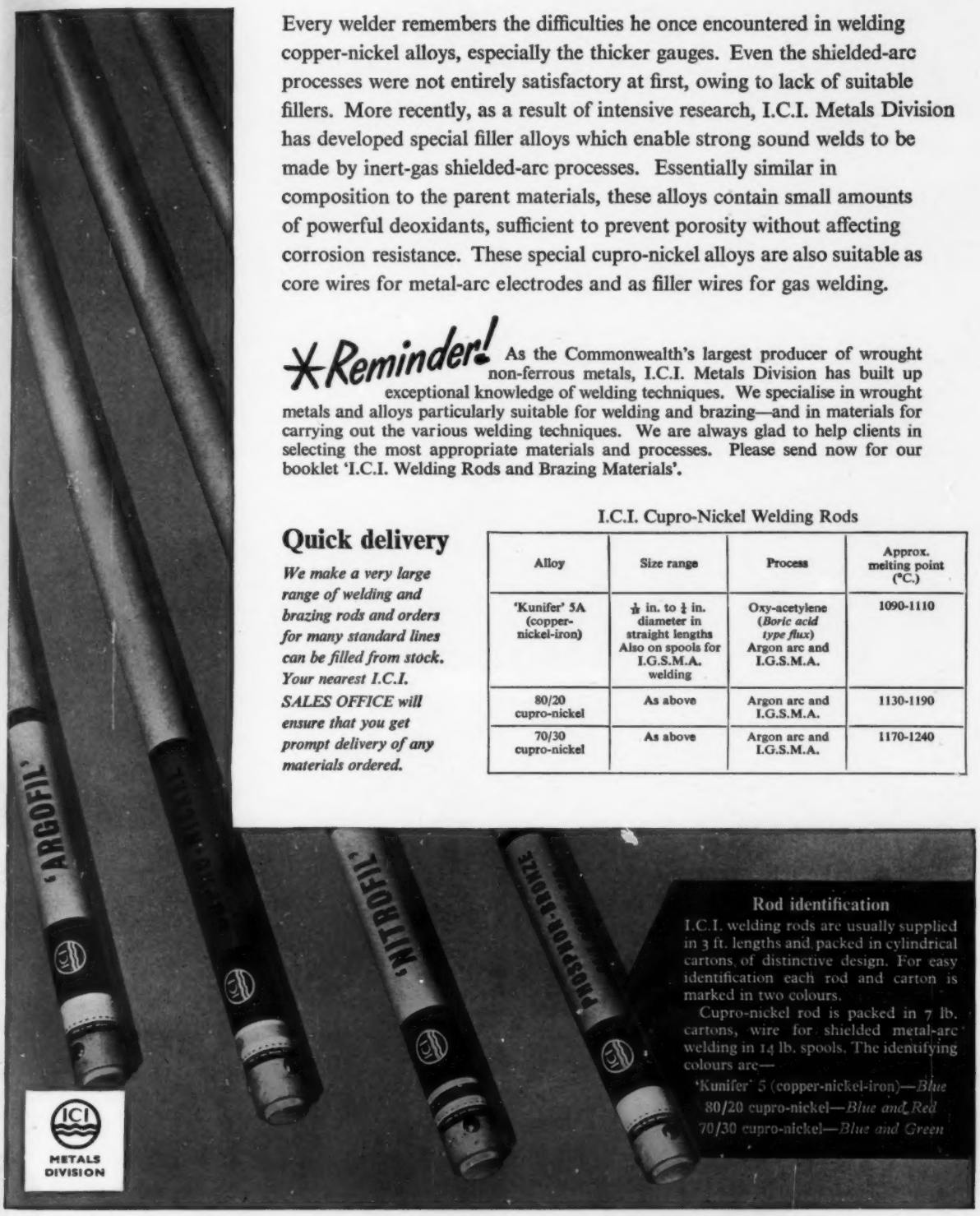
Welding Cupro-Nickel alloys



Every welder remembers the difficulties he once encountered in welding copper-nickel alloys, especially the thicker gauges. Even the shielded-arc processes were not entirely satisfactory at first, owing to lack of suitable fillers. More recently, as a result of intensive research, I.C.I. Metals Division has developed special filler alloys which enable strong sound welds to be made by inert-gas shielded-arc processes. Essentially similar in composition to the parent materials, these alloys contain small amounts of powerful deoxidants, sufficient to prevent porosity without affecting corrosion resistance. These special cupro-nickel alloys are also suitable as core wires for metal-arc electrodes and as filler wires for gas welding.

*Reminder! As the Commonwealth's largest producer of wrought non-ferrous metals, I.C.I. Metals Division has built up exceptional knowledge of welding techniques. We specialise in wrought metals and alloys particularly suitable for welding and brazing—and in materials for carrying out the various welding techniques. We are always glad to help clients in selecting the most appropriate materials and processes. Please send now for our booklet 'I.C.I. Welding Rods and Brazing Materials'.

Quick delivery

We make a very large range of welding and brazing rods and orders for many standard lines can be filled from stock. Your nearest I.C.I. SALES OFFICE will ensure that you get prompt delivery of any materials ordered.

I.C.I. Cupro-Nickel Welding Rods

Alloy	Size range	Process	Approx. melting point (°C.)
'Kunifer' 5A (copper-nickel-iron)	$\frac{1}{16}$ in. to $\frac{1}{4}$ in. diameter in straight lengths Also on spools for I.G.S.M.A. welding	Oxy-acetylene (*Boric acid type flux*) Argon arc and I.G.S.M.A.	1090-1110
80/20 cupro-nickel	As above	Argon arc and I.G.S.M.A.	1130-1190
70/30 cupro-nickel	As above	Argon arc and I.G.S.M.A.	1170-1240

Rod identification

I.C.I. welding rods are usually supplied in 3 ft. lengths and packed in cylindrical cartons of distinctive design. For easy identification each rod and carton is marked in two colours.

Cupro-nickel rod is packed in 7 lb. cartons, wire for shielded metal-arc welding in 14 lb. spools. The identifying colours are—

'Kunifer' 5 (copper-nickel-iron)—*Blue*
80/20 cupro-nickel—*Blue and Red*
70/30 cupro-nickel—*Blue and Green*

IMPERIAL CHEMICAL INDUSTRIES LIMITED, LONDON, S.W.1
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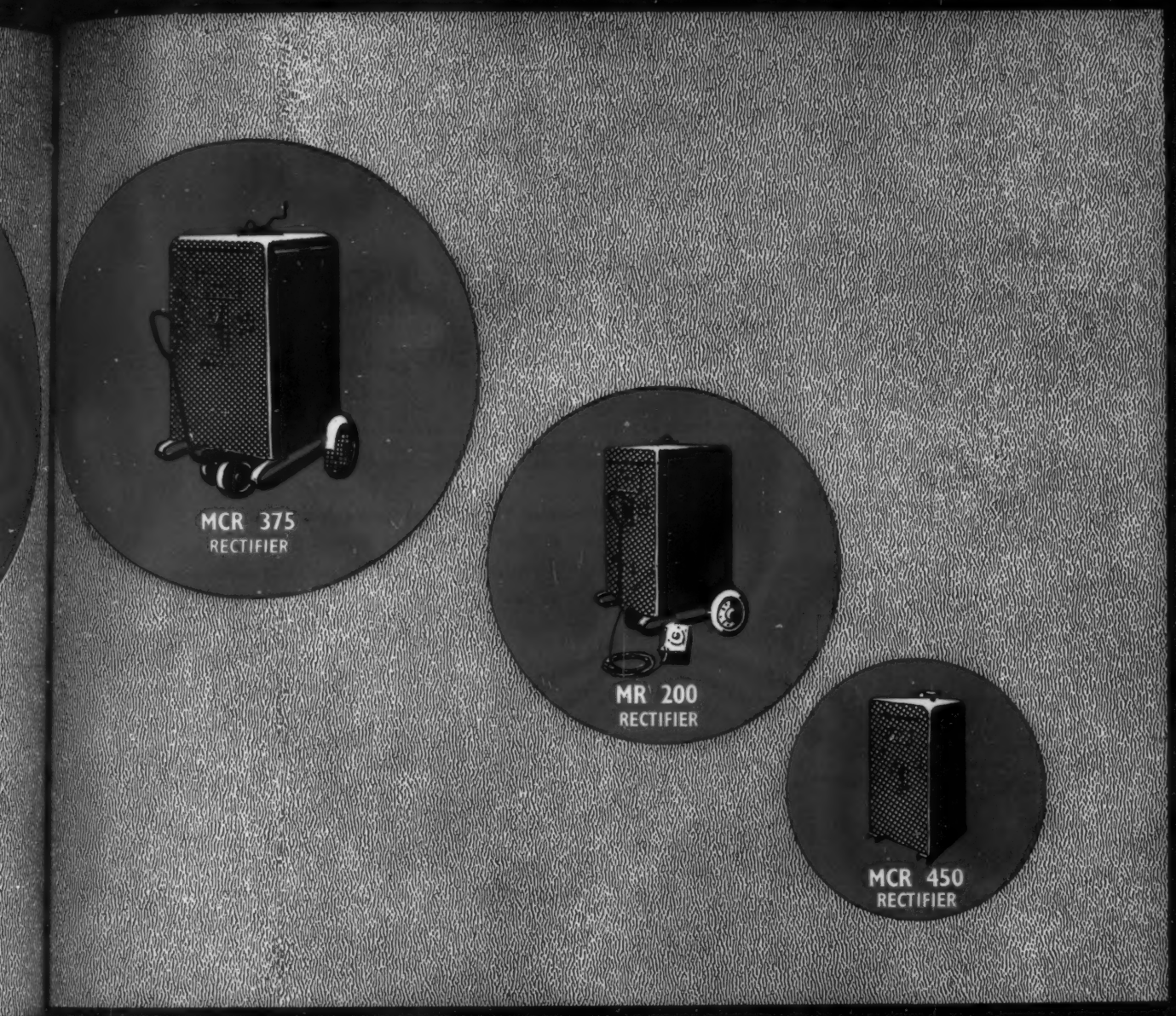
DEB 400
ENGINE-DRIVEN SET

MGB 400
MOTOR GENERATOR SET

Quasi-Arc



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every type for every need

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Low running costs because of small no-load current.

Current range up to 600 amps. for manual welding (1200 amps. for automatic welding).

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Special features of the new design of the MGB 400 set (current range 40–400 amps.): Push-button automatic star delta starter; separate static excitation giving excellent dynamic characteristics and stable arc conditions to suit all types of electrodes; wide open circuit voltage range; independent current and voltage selection; maintenance reduced to a minimum and servicing made extremely easy.

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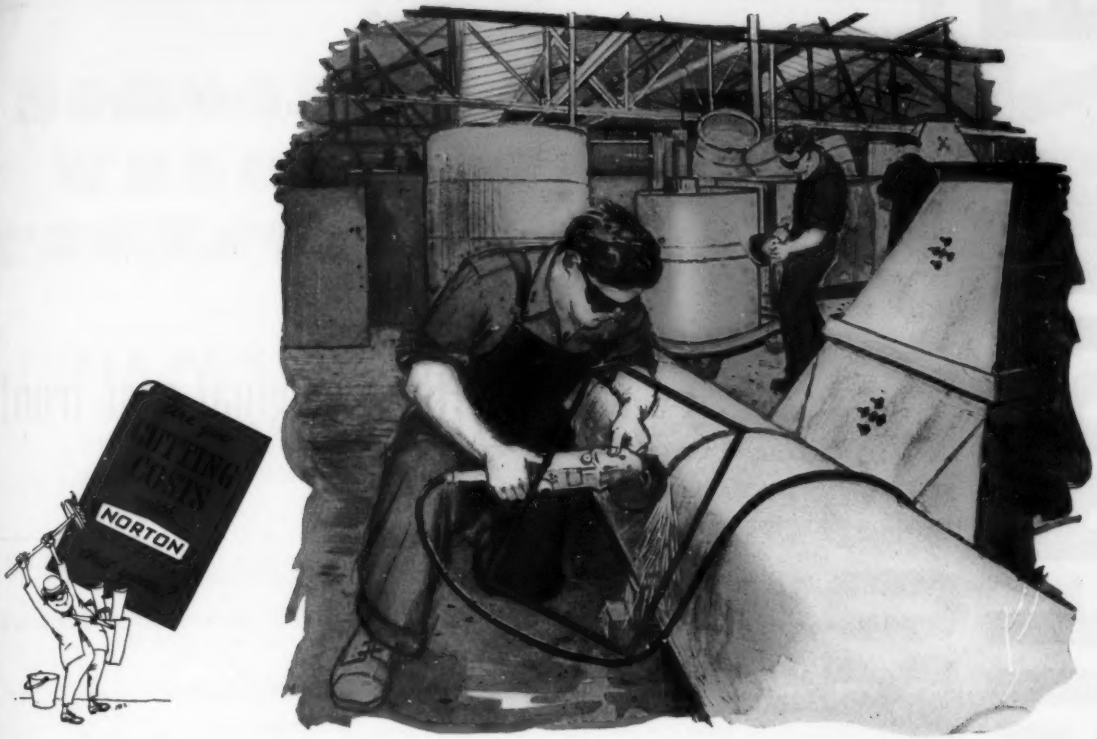

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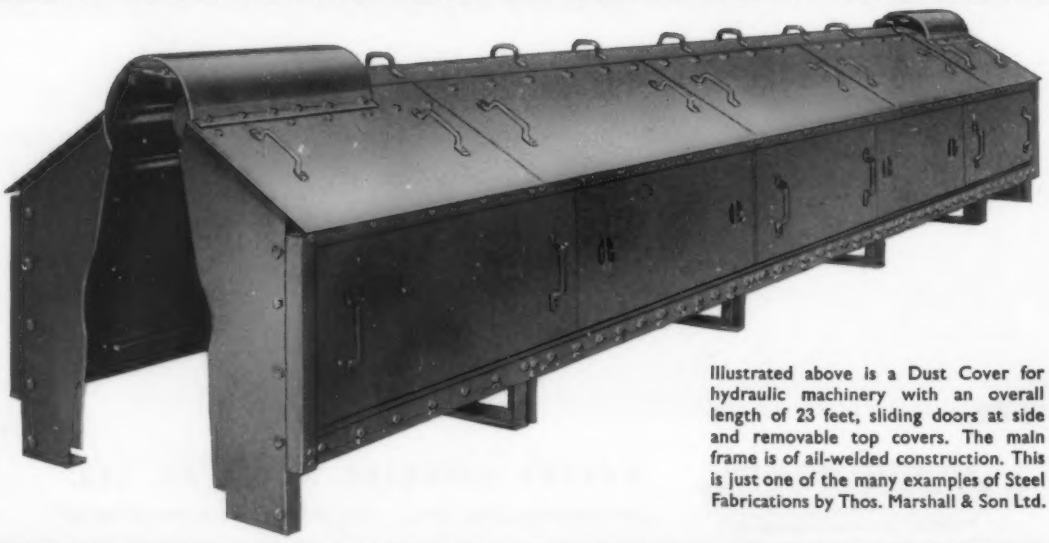

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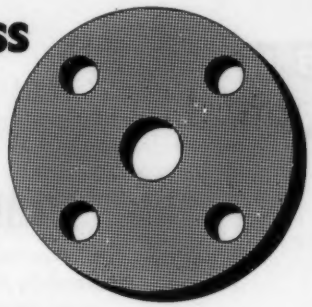

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Johnson, Richard, & Nephew, Ltd. . . . . —
Kodak Ltd.. . . . . —
Lincoln Electric Co. Ltd. 18
Marconi Instruments Ltd. . . . —
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Murex Welding Processes, Ltd. . —
Newton Victor Ltd. . . . . —
Norton Grinding Wheel Co. Ltd. 21
Philips Electrical, Ltd. Inside back cover
Phillips, W. A., Anderson & Co. Ltd. . . . . —
Quasi-Arc Ltd. 14, 15
Radiochemical Centre 6
Robey & Co. Ltd. . . . . —
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Siemens-Schuckert (Great Britain) Ltd. . . . . —
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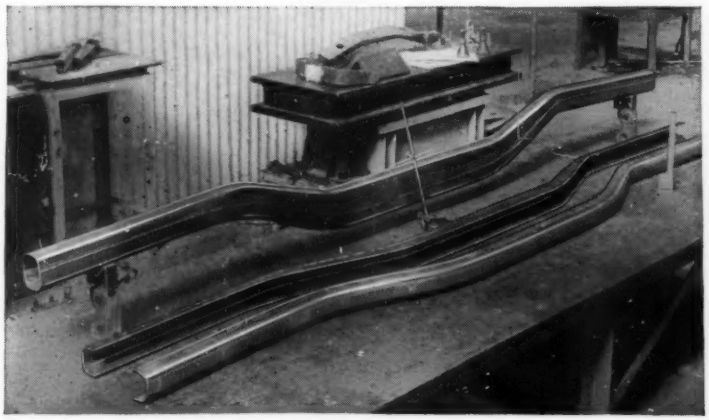

Component parts and finished vehicle chassis side member welded by Philips CO_2 process. *(Photo by courtesy of John Thompson Motor Pressings Ltd.)*

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